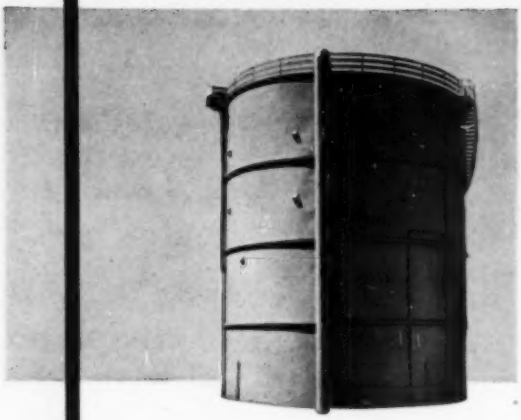
APRIL 1952

Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

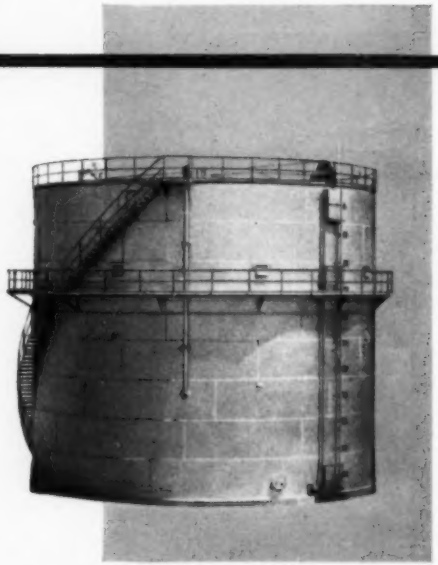
simpler

The Wiggins Gasholder has a remarkably simple design. It has none of the complicated mechanisms of old-type gasholders. No materials that can be harmed by weather.



simplest

Wiggins is the ONLY gasholder that uses no water, no tar, no grease. Wiggins assures no weather worries, no operating costs, no maintenance problems.



simplicity

Wiggins is the only gasholder with an absolutely dry, frictionless seal— gas-tight and impermeable.

Wiggins Gasholder

BY GENERAL AMERICAN

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GENERAL AMERICAN TRANSPORTATION CORPORATION
135 South La Salle Street
Chicago 90, Illinois
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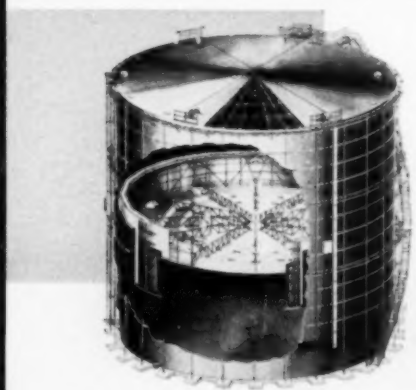

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Volume 48

Number 4

Chemical Engineering Progress

APRIL

1952

OPINION AND COMMENT

Page

THOUGHT FOR FOOD
P. H. Groggins 159

ENGINEERING SECTION

PREVENTIVE MAINTENANCE IN CHEMICAL INDUSTRY
W. E. Chandler 161

DISPERSION FROM SHORT STACKS
C. A. Gosline 165

EVAPORATION FROM DROPS—Part II
W. E. Ranz and W. R. Marshall, Jr. 173

CENTRIFUGAL DISK ATOMIZATION
S. J. Friedman, F. A. Gluckert, and W. R. Marshall, Jr...... 181

APPLICATION OF RADIOACTIVE TRACERS TO DIFFUSIONAL OPERATIONS
H. E. Hughes and J. O. Maloney 192

INDUSTRY AND COLLEGE CAN COOPERATE!
W. T. Nichols 201

ADEQUACY AND STANDARDS OF ENGINEERING EDUCATION..... 206

CAST ALLOY REFERENCE SHEET (No. 8)
N. S. Mott 208

NEWS

	Page		Page
FRENCH LICK MEETING	33	MARGINAL NOTES	64
ATLANTA MEETING	34	LOCAL SECTION NEWS	68
INDUSTRIAL NEWS	44	FUTURE MEETINGS	74
DATA SERVICE 49-52		NEWS ABOUT PEOPLE	75
A.I.Ch.E. CANDIDATES	58	CLASSIFIED SECTION	80
SECRETARY'S REPORT	61	NECROLOGY	82

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magnetic coupling

A BASIC ADVANCE IN INSTRUMENTATION

. . . eliminates the stuffing box

. . . ideal for difficult fluids

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SAFE
PRECISE

The FLOWRATOR flow meter, combined with the patented separation-proof MAGNABOND magnetic coupling, provides the best means of metering any fluid. The MAGNABOND coupling picks up the FLOWRATOR metering float position without the need for stuffing boxes or torque tubes, thus providing an ideal solution for problems of metering corrosive or explosive liquids, slurries, or fluids under high pressure or temperature. The MAGNABOND coupling can operate indicators, recorders, totalizers, recording controllers, or pneumatic transmitters in various combinations—in close-coupled or remote instruments.

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SALES ENGINEERING OFFICES THROUGHOUT THE WORLD

CORROSION

CHEMICAL RESISTANCE OF "KARBATE" PRODUCTS

This table shows the grade of "Karbate" Impervious Graphite and the type of "National" Resin Base Cement recommended for commercial use in the more common corrosive chemicals. The concentrations and temperatures listed are based on field and laboratory experience, but *the satisfactory use of these materials is not limited to the chemical reagents or conditions shown in this table.*

Chemical Reagent	Concentration	Fluid Temperatures up to	Recommendation: Grade	Recommendation: Cement
ACIDS				
Acetic acid	All	Boiling	22	14
Acetic anhydride	100%	Boiling	22	14
Arsenic acid	All	Boiling	22	14
Boric acid	All	Boiling	22	14
Carbonic acid	All	200° F	22	14
Chromium trioxide, aq. soln.	0-10%	Boiling	22	14
Citric acid	All	Boiling	22	14
Formic acid	All	Boiling	22	14
Hydrobromic acid	All	Boiling	22	14
Hydrochloric acid	All	Boiling	22	14
Hydrofluoric acid	0-40%	185° F	x	14
Hydrofluoric acid	40-60%	—	22	14
Hydrofluoric acid	Over 60%	Boiling	22	14
Hydrofluoric acid	All	Boiling	22	14
Hydrogen sulphide-water	All	212° F	22	(†)
Lactic acid	100%	185° F	22	(†)
Monochloracetic acid	0-10%	140° F	x	14
Nitric acid	10-20%	—	22	14
Nitric acid	Over 20%	Boiling	22	14
Nitric acid	100%	Boiling	22	14
Oleic acid	All	Boiling	21	14
Oxalic acid	0-85%	Boiling	22	(†)
Phosphoric acid	100%	Boiling	22	
Stearic acid	0-75%	338° F	x	14
Sulfuric acid	75-96%	—	22	14
Sulfuric acid	Over 96%	Room	22	
Sulfurous acid	All	Boiling		
Tartaric acid	All			
ALKALIES				
Ammonium hydroxide	All	Boiling	22	15
Monoethanolamine	All	Boiling	22	15
Sodium hydroxide	0-67%	Boiling	21	15
Sodium hydroxide	67-80%	275° F	21	15
Tetramine C	All	Boiling		
SALT SOLUTIONS				
Aluminum Chloride	All	Boiling	22	14
Ammonium thiocyanate	0-63%	Boiling	22	x
Arsenic trichlorida	100%	230° F	22	14
Calcium chlorate	0-10%	140° F	22	14
Calcium hypochlorite	All	90 °F	22	14
Cupric chloride	All	Boiling	22	14
Ferric chloride	All	Boiling	22	14
Ferrous chloride	All	Boiling	22	14
Ferrous sulphate	All	Boiling	22	14
Manganous sulphate	All	Boiling	22	14
Nickel chloride	All	Boiling	22	14
Nickel sulphate	100%	Boiling	22	14
Phosphorus trichloride	All	Boiling	22	14
Sodium chloride	0- 4%	Room	21	14
Sodium chlorite	0-25%	Boiling	22	14
Sodium hypochlorite	All	Boiling	22	14
Stannic chloride	All	Boiling	22	14
Zinc ammonium chloride	All	Boiling	22	14
Zinc chloride	All			
Zinc sulfate	All			
HALOGENS, AIR, WATER				
Air	—	338° F	x	14
Bromine	100%	Boiling	22	14
Bromine water	All	Room	22	14
Chlorine—dry	100%	Boiling	22	14
Chlorine water	All	Room	x	
Iodine	100%		x	
Fluorine	100%			

Chemical Reagent	Concentration	Fluid Temperatures up to	Recommendation: Grade	Recommendation: Cement
HALOGENS, AIR, WATER cont.				
Steam	—	338° F	22	14
Water	—	Boiling	22	14
ORGANIC COMPOUNDS				
Acetone	0-100%	Boiling	22	14
Amyl alcohol	100%	Boiling	22	14
Aniline	0-60%	338° F	22	14
Aniline hydrochloride	100%	Boiling	22	14
Benzene	100%	212° F	22	14
Benzene hexachloride	100%	Boiling	22	14
Butyl alcohol	0-100%	Boiling	22	14
Butyl "Cellosolve"*	100%	Boiling	22	14
Carbon tetrachloride	0-100%	257° F	22	14
"Cellosolve"*	100%	Boiling	22	14
Chlorethylbenzene	100%	140° F	22	14
Chloroform	—	338° F	22	14
Dioxidine	100%	Boiling	22	14
Dowtherm	0-100%	Boiling	22	14
Dioxan	0-100%	122° F	22	14
Ethyl alcohol	0-8%	200° F	22	14
Ethylene chlorohydrin	100%	Boiling	22	14
Ethylene dibromide	100%	Boiling	22	14
Ethylene dichloride	Saturated	Room	22	14
Ethyl mercapton—water	100%	Boiling	22	14
Freon 11 and 12	100%	338° F	22	14
Gasoline	0-100%	Boiling	22	14
Glycerine	100%	Boiling	22	14
Isopropyl acetate	0-100%	Boiling	22	14
Isopropyl alcohol	100%	Boiling	22	14
Isopropyl ether	100%	Boiling	22	14
Kerosene	All	Boiling	22	14
Mannitol	100%	Boiling	22	14
Methyl isobutyl ketone	0-100%	Boiling	22	14
Methyl alcohol	100%	Boiling	22	15
Monochlor benzene	100%	Boiling	22	14
Octyl alcohol	100%	Boiling	22	14
Perchlorbenzene	100%	Boiling	22	14
Paraldehyde	100%	Boiling	22	14
Tetrachlorethane, sym.	100%			
Trichlorethylene				
MIXTURES				
Ammonium persulfate plus sulfuric acid	25%	Room	22	14
Calcium chloride plus calcium chlorate	39%	140° F	22	14
Chlorinated ethyl alcohols	30%	Boiling	22	15
Chrome plating solns.	10%		x	
Hydrochloric acid sat. with chlorine	All	Boiling	22	14
Nickel plating solns. (chloride)	Over 20%			
Nickel plating solns. (sulfate)	All	Boiling	22	14
Nitric acid plus hydrofluoric acid	All	Boiling	22	14
Oxkite acid materials—O.C. 32, O.C. 33, O.C. 36, O.C. 84A, O.C. 84M, CRYS. 87, O.C. 88	All	140° F	22	(†)
Parkerizing solution	15%			
Rayon Spin bath	5%			
Sodium hypochlorite plus sodium hydroxide	All	Boiling	22	14
Sulfuric acid plus citric acid	All	Boiling	22	14
	All	Boiling	21	14
	0-25%	Boiling	x	—
	96%			
	93%			

(x) Not recommended

NOTE: (†) "National" No. 14 Cement used with threaded joints will give serviceable life.
(*) The term "Cellosolve" is a registered trade-mark of Union Carbide and Carbon Corporation.

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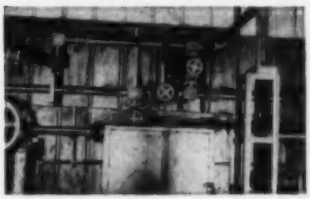
IMMUNE TO THERMAL SHOCK • LIGHT WEIGHT • NO METALLIC CONTAMINATION • LONG LIFE—LOW MAINTENANCE

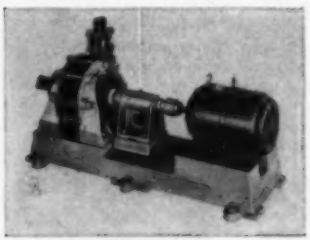
HEAT EXCHANGERS

Wide variety of standard and custom built models in time-proven designs. Shell and tube, cascade, concentric and immersion types available in stock sizes. High rates of heat transfer. Catalog Sections S-6620, S-6690, S-6715, S-6716, S-6750, S-6780.



PIPE, FITTINGS AND VALVES

Complete standard line to handle your toughest fluid conveying requirements. Easy to install and maintain with simple hand tools. Catalog Section S-7000.



PUMPS

The centrifugal pump for handling corrosive fluids—rugged design, simple construction, trouble-free rotary seal. Handling capacities to 800 G. P. M. Catalog Section S-7200.

TOWERS

"Karbate" impervious graphite towers for absorption, fractionation, extrusion, scrubbing and many other processing operations. Easily erected from standardized monolythic sections and components. Catalog Section S-7350.

BRICK

Accepted material for lining tanks, towers, digesters and other vessels containing corrosive chemicals. Catalog Section S-6210.

HCL COMBUSTION CHAMBERS

Versatile, standardized line for hydrogen chloride synthesis. Burns moist gas. Simplicity of operation. Catalog Section S-7530.

STEAM JETS

Withstand severe corrosive conditions and thermal shock in heating and agitating corrosive solutions by direct injection of steam. Catalog Section S-7300.

GROUND ANODES

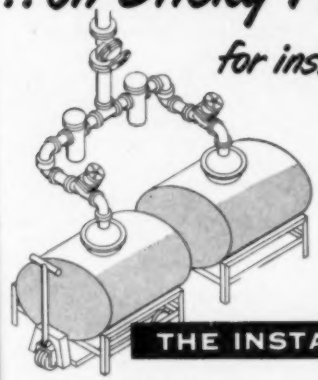
"National" Graphite Ground Anodes for cathodic protection of buried, submerged or exposed metallic structures provide for control of current input to meet specific environmental conditions. Catalog Section S-6510.

HCL ABSORBERS

Standard and custom built models to meet *any* hydrochloric acid production requirement. Falling-film principal of absorption — proven efficient and compact design. More HCL produced in "Karbate" absorbers than in all other types combined. Catalog Section S-7430.

Do Your Valves Fit Your Job This Well?

... on Sticky Fluid for instance



THE INSTALLATION

Crane Diaphragm Valves on air pressurized liquid latex piping service in paint factory, Adams & Elting Division, The Glidden Company, Chicago.

THE HISTORY

Conventional valves formerly used in this service were hindered by exposure of working parts to the line fluid. The sticky latex would accumulate in the bonnet and stem threads, freezing the stem, and making valve operation difficult or impossible. With 10 or more operating cycles required daily, the plant faced considerable valve trouble and maintenance expense.

Both trouble and maintenance cost were completely eliminated by replacing with Crane Diaphragm Valves. Their fully sealed bonnet keeps the latex out of working parts. They operate smoothly and do not freeze or stick. So well is the customer satisfied with Crane Diaphragm Valves, more have been ordered for new latex lines.

VALVE SERVICE RATINGS

OPERATION:	Easy - No sticking
SUITABILITY:	Fluid can't get into bonnet
MAINTENANCE COST:	None to date - None indicated
SERVICE LIFE:	No sign of wear
OPERATING RESULTS:	Production delays stopped
PRICE:	In line - No premium
AVAILABILITY:	Stock item in Crane line

THE VALVE

Crane No. 1610 Iron Body Packless Diaphragm Valves featuring separate disc and diaphragm. Neoprene diaphragm acts as bonnet seal only; isn't pinched or stressed when valve is closed. Conventional type seating makes positive closure even should diaphragm fail. High flow capacity Y-pattern body has non-restricting interior design. Available unlined or fully Neoprene lined. Consult your Crane Catalog or Crane Representative.

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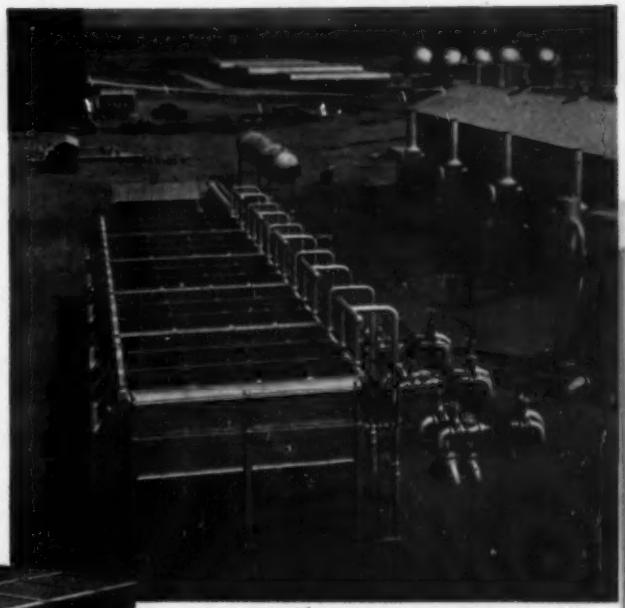
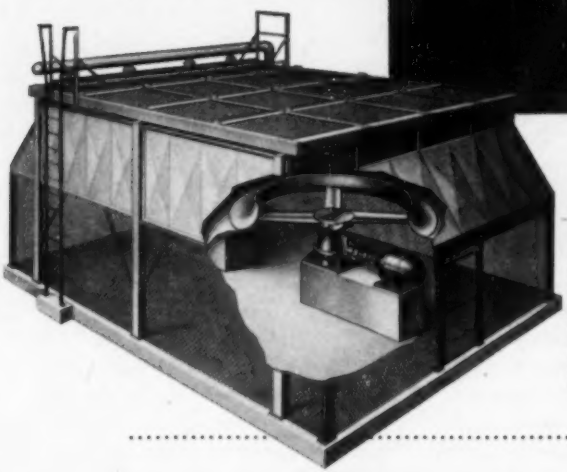
make your own comparison...

a Fluor-GR Fin-Fan

against any other air-cooled heat exchanger

When considering air-cooled heat exchanger equipment, compare the advantages of a Fluor-GR Fin-Fan. Make comparisons of structural simplicity and flexibility. Compare the exclusive features of the Griscom-Russell K-Fin section, the rugged yet precision design of Fluor mechanical equipment. Check *proven performance* in such varied services as gas transmission systems, petroleum refineries, light hydrocarbon processing plants, chemical processing plants, and power and industrial plants. Before you buy or specify, compare the Fluor-GR Fin-Fan. A Fin-Fan provides more exclusive design features —features that add up to *efficient, dependable* performance—than any other make of air-cooled heat exchanger. Write for Fluor Bulletin No. FF-8501.

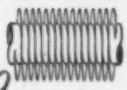




Compare

structural design

Structurally, the Fin-Fan is the ultimate in simplicity and flexibility. Its "truss-type" design provides a rugged, vibrationless unit, free of extraneous parts. Uniform prefabrication of parts, with bolt holes and orientation incorporated in basic design, permits easy extension without shut-down of existing units!



Compare

K-Fin features

G-R K-Fins are tension-wound for moderate temperatures, rolled into grooves for elevated temperatures. Threaded header plugs provide quick, easy access to tube ends for cleaning or replacement. Plugs are shoulder-tight to form a leakproof metal-to-metal joint at all pressures, independent of thread tightness.

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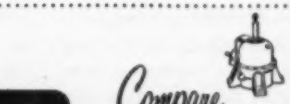
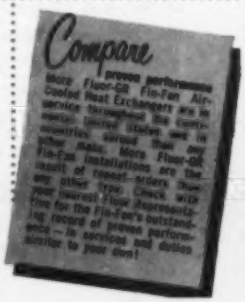


Compare

mechanical equipment

Fluor mechanical equipment is ruggedly designed to meet specific heat transfer requirements. 4 basic gear units cover 4 different and distinct horsepower ranges. This, coupled with a choice of fan assemblies ranging from 8' to 20' in diameter, with 4 or 6 blades per fan unit, enables the proper combination of gears and fans to effect optimum efficiency.


Compare
proven performance
More Fluor-GR Fin-Fan Air-Cooled Heat Exchangers are in service throughout the continental United States and in countries around the world than any other make. More Fluor-GR Fin-Fan installations are the result of repeat orders than any other type. Check with your nearest Fluor Representative for the Fin-Fan's outstanding record of proven performance—in services and duties similar to your own!

Put In Less...Take Out More—

SEQUESTER IRON with

Pfizer Sodium Gluconate

● Here's the proof that you put in less...take out more when you sequester iron with Pfizer Sodium Gluconate, Technical. On this chart are the results of a recent study in our laboratories on the iron sequestering power of various sequestering agents. Of the four chemicals on the chart, you will note that Sodium Gluconate exhibited by far the best results in sequestering the ferric ion over a wide range of pH. Pfizer Sodium Gluconate, Technical, is a stable, free-flowing, tan-colored, crystalline powder. It is available in 100-lb. multi-wall paper bags. Try the sequestering agent with proved results. "Put in *less sequestering agent*...take out *more iron*"...with Pfizer Sodium Gluconate, Technical. Contact Pfizer today for more detailed information about this study. Call or write:

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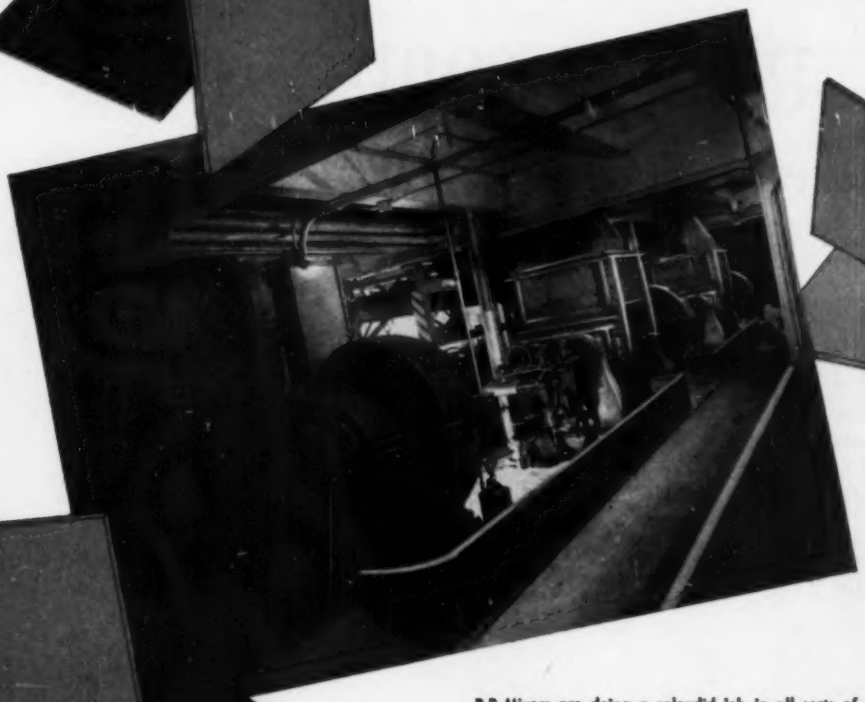
Manufacturing Chemists for Over 100 Years

PFIZER QUALITY

PFIZER

Colorful asphalt floor tile mix uniformly produced in BAKER PERKINS mixers

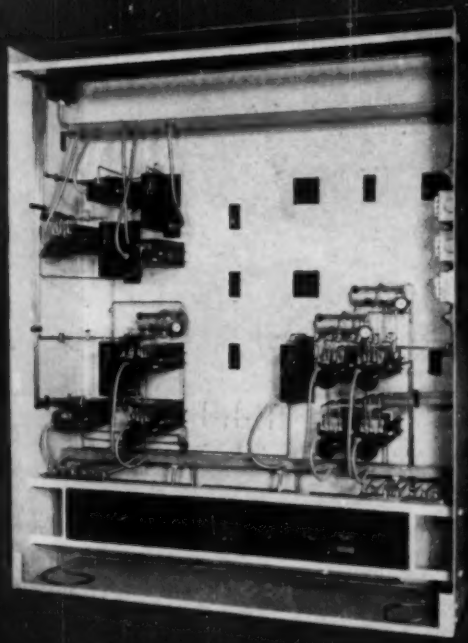


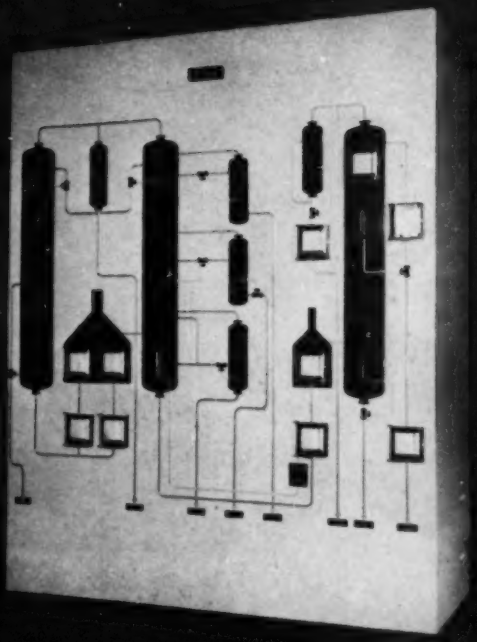
B-P Mixers are doing a splendid job in all sorts of processing operations, and this installation of six size 15JSE BAKER PERKINS Mixers at a large asphalt floor tile plant is an excellent example. These six mixers can thoroughly blend the ingredients for asphalt floor tile at the rate of 18,000 lbs. per hour on a continuous production schedule. Like other BAKER PERKINS equipment, the cost of operating and maintenance, including labor, material handling, power, and depreciation, are down where they should be. BAKER PERKINS equipment can help cut costs, increase production, and improve the quality of your product, too. Consult a B-P sales engineer or write us today.

BAKER PERKINS INC.
CHEMICAL MACHINERY DIVISION
SAGINAW, MICHIGAN

Graphic panels for your process control...

engineered and custom-built by Honeywell





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TEL-O-SET MINIATURE RECORDERS, INDICATORS AND CONTROLLERS

Specifically designed for graphic panel use, the Tel-O-Set family of instruments packs a lot of performance and quality into space-saving construction.

TEL-O-SET RECORDER:

Mounts on six-inch centers. Provides a continuous record of process variable. All adjustments are accessible from front of panel. By means of a knob and switches, the control air pressure loading and set point can be obtained, or an operator can switch from automatic to manual operation and back to automatic without upsetting the process.

TEL-O-SET CONTROLLER:

Available in a variety of models with fixed or adjustable proportional band, fast or slow reset rate, with or without bypass relay. Offers economy of selection, for control of process variables such as flow, temperature, and pressure.

TEL-O-SET INDICATOR:

A compact circular-dial indicator for displaying the measured value where continuous recording is not required. Fits same size panel cutout and has same pneumatic switching arrangements as Tel-O-Set Recorder.

LIQUID LEVEL INDICATOR:

Compact and rugged, this vertical-scale instrument indicates liquid level continuously. Easily-read scale needs no external illumination.

ELECTRONIC PNEUMATIC TEMPERATURE TRANSMITTER

This transmitter converts the electrical signal from a thermocouple into a variable air pressure which is transmitted to Tel-O-Set instruments. It uses the performance-proved components of *ElectroniK* instruments. Compact, readily mounted behind the panel.

GRAPHIC PANELS—nerve centers of modern processing units—are setting new high standards for convenience and efficiency in process control. And, you profit fully by centralization when you take advantage of the functional design and instrumentation of ColorGrafic panels by Honeywell. Here are some of their outstanding features:

Broad selection of instruments: A full line of indicators, recorders and controllers . . . both miniature units for incorporation in the process diagram, and conventional units for supplementary detailed data. Equipment covers all process variables . . . including sensing elements, remote transmitters and control valves.

Complete panel engineering and construction facilities: Honeywell engineers, working in close cooperation with your staff, design integrated panels for the specific requirements of your individual process. The control boards are assembled in Honeywell's extensive panel shop, then are shipped complete, with all instruments in place, fully wired, piped and tested . . . ready to connect to plant equipment. You save substantially . . . in engineering and installation time.

Your local Honeywell engineer will be glad to discuss how ColorGrafic panels can be applied to your processes. Call him in today . . . he is as near as your phone.

MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, 4427 Wayne Ave., Philadelphia 44, Pa.

MINNEAPOLIS
Honeywell
BROWN INSTRUMENTS

First in Controls

● *Important Reference Data*

Write for Bulletin No. 85-20, "Centralized Instrumentation . . . unlimited."

How Celite Mineral Fillers make a product free-flowing . . .

Keeping fertilizers "On the run"

REALIZING their product is one that cannot "cake-up" and still survive in a competitive market, leading producers of fertilizer use one of the Celite Mineral Fillers as a standard "anti-caking" ingredient.

The ability of Celite Fillers to keep a product free-flowing results from their high absorption properties and unique diatom structure—properties which make them unusually effective safeguards against caking in deliquescent materials. They are two of the unusual physical characteristics that adapt these diatomaceous silica powders to numerous industrial uses.

THESE CELITE PROPERTIES BENEFIT MANY TYPES OF PRODUCTS

Because of their inertness and great bulk per unit of weight, Celite Mineral Fillers make ideal bulking agents for powders and pastes. Their tiny multi-shaped particles interlace to stiffen and strengthen admixtures. The microscopically small facets of these particles diffuse light so effectively that they can be utilized to impart any desired degree of flatness to a surface film. Their light, porous nature improves suspension, helps prevent segregation. And their porous, thin-walled cellular structure imparts a delicate non-scratching abrasive action.

You may find Celite the "extra something" needed to lift your product above competition. Why not discuss its application to your problem with a Celite engineer? Or write for further information and samples to Johns-Manville, Box 60, New York 16, N. Y. In Canada: 199 Bay St., Toronto, Ont.

CHECK LIST OF PRODUCT BENEFITS OBTAINABLE AT LITTLE COST WITH CELITE MINERAL FILLERS

- Added Bulk
- Better Suspension
- Faster Cleaning Action
- Greater Absorption
- Improved Color
- Better Dielectric Properties
- More Durable Finish
- Increased Viscosity
- Elimination of Caking
- Higher Melting Point
- Better Dry Mixing
- Improved Dispersion

Johns-Manville CELITE®

MINERAL FILLERS

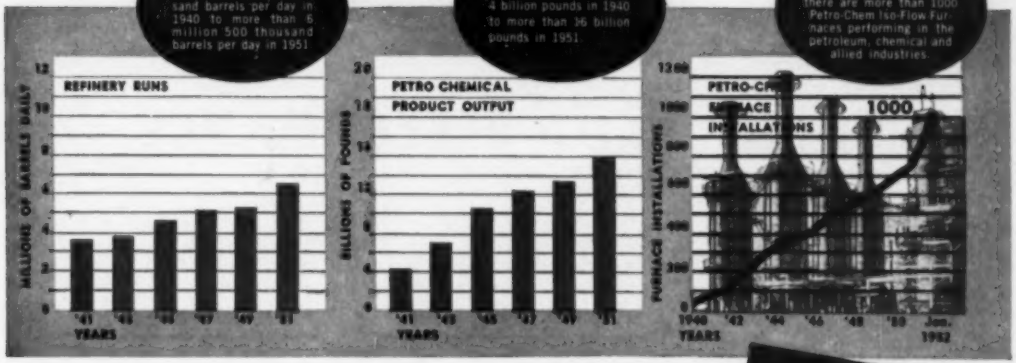
CONFIDENCE spells growth

There's many a reason for the parallel growth of the Petro Chemical Industry and the increasing use of Petro-Chem Iso-Flow Furnaces by leading Petro Chemical Companies.

Runs to stills in U. S. oil refineries increased from 3 million 500 thousand barrels per day in 1940 to more than 6 million 500 thousand barrels per day in 1951.

Petro Chemical production has increased from 4 billion pounds in 1940 to more than 36 billion pounds in 1951.

In 1940 there was 1 In 1946 there were 400 and as of Feb 1952 there are more than 1000 Petro-Chem Iso-Flow Furnaces performing in the petroleum, chemical and allied industries.



ISO-FLOW FURNACE USERS KNOW . . . that the Petro-Chem Development Company has but one basic product; processing furnaces for petroleum, chemical and allied industries. As a result of experience, they know that it does not pay to build their own furnaces; that Petro-Chem Iso-Flow Furnaces cost less, operate efficiently and usually beyond their rated capacity . . . they know that all process data made available for the design and engineering of Petro-Chem Iso-Flow Furnaces is kept strictly confidential . . . never released by Petro-Chem Development Company engineers.

The Petro Chemical, Petroleum, Chemical and allied industries can be confident that as they grow in size and advance in technology, so Petro-Chem Iso-Flow Furnaces will keep pace.

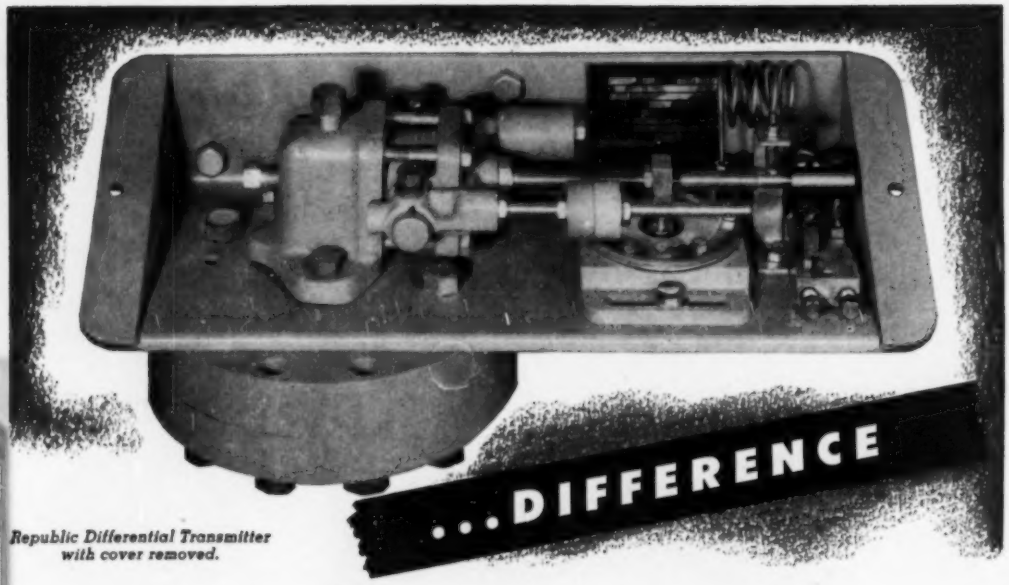
There's a PETRO-CHEM ISO-FLOW FURNACE for every process requirement of the petroleum and chemical industries for any DUTY TEMPERATURE PRESSURE EFFICIENCY

PETRO-CHEM ISO-FLOW FURNACES

UNLIMITED IN SIZE . . . CAPACITY . . . DUTY

PETRO-CHEM DEVELOPMENT CO., INCORPORATED

Bethlehem Supply, Tulsa and Houston · Flagg, Brackett & Durgin, Boston · D. D. Foster, Pittsburgh
Faville-Levally, Chicago · Lester Oberholtz, California · Gordon D. Hardin, Louisville, Kentucky



Republic Differential Transmitter with cover removed.

Spells *PLUS* PERFORMANCE

The Republic Pneumatic Transmitter combines machine ruggedness with instrument precision to provide matchless performance in measuring flow, level, pressure or density of a wide variety fluids. By any or all of the following points, the Republic challenges comparison:

ACCURACY of the Republic force-balance principle is higher than can be consistently secured and maintained with any other method. 1/2 of 1% guaranteed.

TEMPERATURE variations of ambient atmosphere have negligible effect on the accuracy of the Republic transmitter.

CHANGES IN AIR SUPPLY PRESSURE do not affect the accuracy of a Republic transmitter to any significant extent. A 5 psi change produces an error of less than 1/10%.

CHANGES IN LINE PRESSURE—Republic differential transmitters are not affected by variations in line pressure. A patented and exclusive simple adjustment assures this protection.

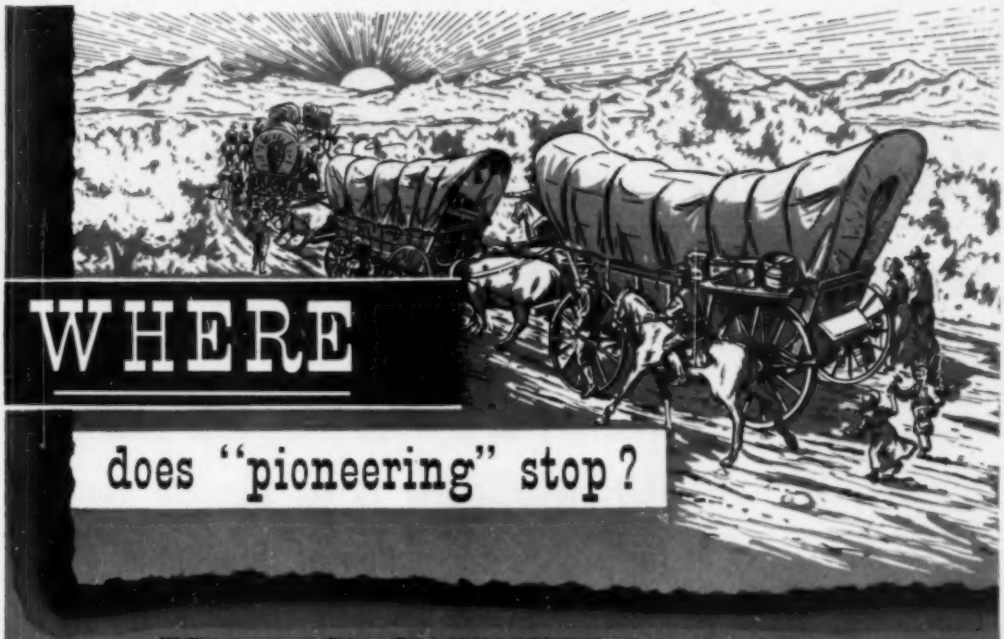
SENSITIVITY—Due to the negligible motions required for complete operation of all parts, for a full scale change, no appreciable hysteresis results from reversal of direction of measurement change.

VIBRATION of any normal frequency has no effect on the Republic transmitter.

LEVELING—Since all parts are balanced, and no liquid is used for calibration, Republic transmitters need not be leveled exactly, and may be adjusted for installation in any position.

FOR TWELVE YEARS Republic Pneumatic Transmitters have delivered unmatched performance in every type of installation. Complete details of design and operation, plus numerous application suggestions are combined in Data Book, 1002. Send for your copy, today.

REPUBLIC FLOW METERS CO.
2240 Diversey Parkway, Chicago 47, Illinois



WHERE

does "pioneering" stop?

Well . . . we can tell you that with us it never stops.

Even after developing low-cost ozonaire ozone, Welsbach continues to "pioneer" in ozone research . . . extending Welsbach know-how to help potential users find the effective application of ozone to their particular problems.

The numerous commercial applications of Welsbach Ozone are conclusive evidence that it is fast becoming the *preferred* oxidant. In chemical processing, in industrial waste treatment, in water purification—in fact, wherever an oxidant is required—Welsbach Ozone should be considered. And Welsbach engineering know-how is at your service . . . when and if you want it.

If oxidation is a step in your process, investigate Welsbach Ozone. It is a truly low-cost, efficient oxidant . . . with these plus features:

No storage problem; no procurement problem; no materials handling.

No full-time supervision or labor required.

Generated at point of use with equipment requiring little space.

And constant, predictable operating cost.

INCREASE YOUR PROFIT
by lowering costs with economical, dependable

WELSBACH OZONE

Write for information to

THE WELSBACH CORPORATION
ZONE PROCESSES DIVISION
2409 W. Westmoreland St. • Philadelphia 29, Pa.

Pioneers in Continuing Ozone Research

Here's what we meant by

Need help IN MAKING FILTERAIDS GO FARTHER?

A survey by a Dicalite Engineer enabled this manufacturer to cut filteraid usage by 66⅔% per gallon of throughput

One of the many products in this manufacturer's line is varnish. It was being filtered by precoat only, using 100 lbs. of filteraid to deposit on the cloths of a 200-sq. ft. plate and frame press before starting to filter each 1000-gal. batch. A survey by a Dicalite engineer led to saving both time and filteraid. First, a switch was made to a higher-flowing grade of Dicalite filteraid. Only 25 lbs. of this material (Dicalite 4200) was used for the precoat, but 75 lbs. were used in continuous addition to the varnish as it was being filtered. In this way 3,000 gallons were filtered with satisfactory clarity before the press needed cleaning. RESULT: 1) 100 lbs. of Dicalite filtered 3,000 gallons instead of the 1,000 gallons put through by the former method; 2) cycle length was tripled, so that two press cleanings were eliminated in filtering 3,000 gallons and saved considerable down time and overtime. Such spectacular savings are not always possible, but our engineers find many cases where filteraid consumption could be reduced 10% to 15% without any ill effects to operation or product quality. If you feel that a check of your filtration operation or stretching your available supply of filteraid will be helpful, or if you have a current filteration problem, write our nearest office. A Dicalite engineer will gladly call at your convenience.

Send for free copy of Bulletin B-12

DICALITE® FILTERAIDS

DICALITE DIVISION, GREAT LAKES CARBON CORPORATION

GLC

NEW YORK 17, N. Y. • CHICAGO 1, ILL. • LOS ANGELES 17, CALIF.

ADVANCED CONSTRUCTION OF *Buflovak* EVAPORATORS GIVE

Buflovak Evaporators offer the chemical industry efficient evaporation of processing, high capacity and maximum recovery of solids. All of these because of advanced scientific design in every BUFLOVAK Evaporator!

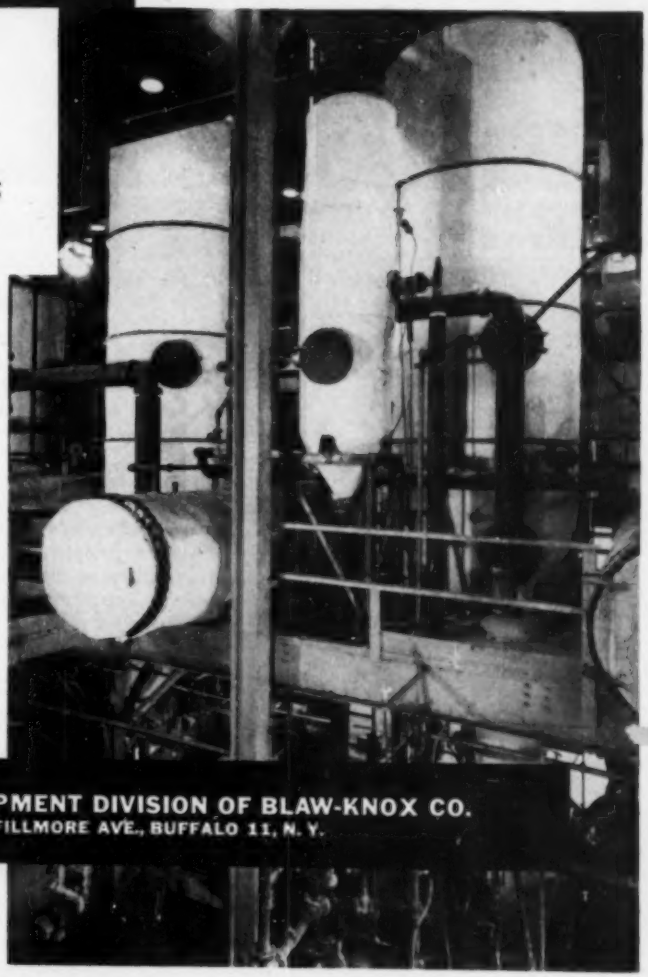
Modern design insures maximum capacity, virtually complete recovery of all solids, and low operating costs. Automatic controls maintain a high level of operating efficiency, and simplify operation . . . all with their profit-building advantages.

✓ *HIGH RATE OF EVAPORATION*

✓ *MAXIMUM RECOVERY OF SOLIDS*

✓ *SIMPLIFIED OPERATION*

BUFLOVAK Triple Effect, Forced Circulation Evaporator with built-in Salt Separators. Used to concentrate caustic and to recover salt crystals from the process. This unit produces 90 tons of 100% NaOH in a 50% solution from cell liquor. Horizontal heating elements afford complete tube accessibility. The tubes are always completely filled with liquor. Flashing cannot occur. Unit is built of nickel and nickel clad steel.



BUFLOVAK EQUIPMENT DIVISION OF BLAW-KNOX CO.
1567 FILLMORE AVE., BUFFALO 11, N. Y.

continuous
indirect heat

Calciner and Cooler . . . . .

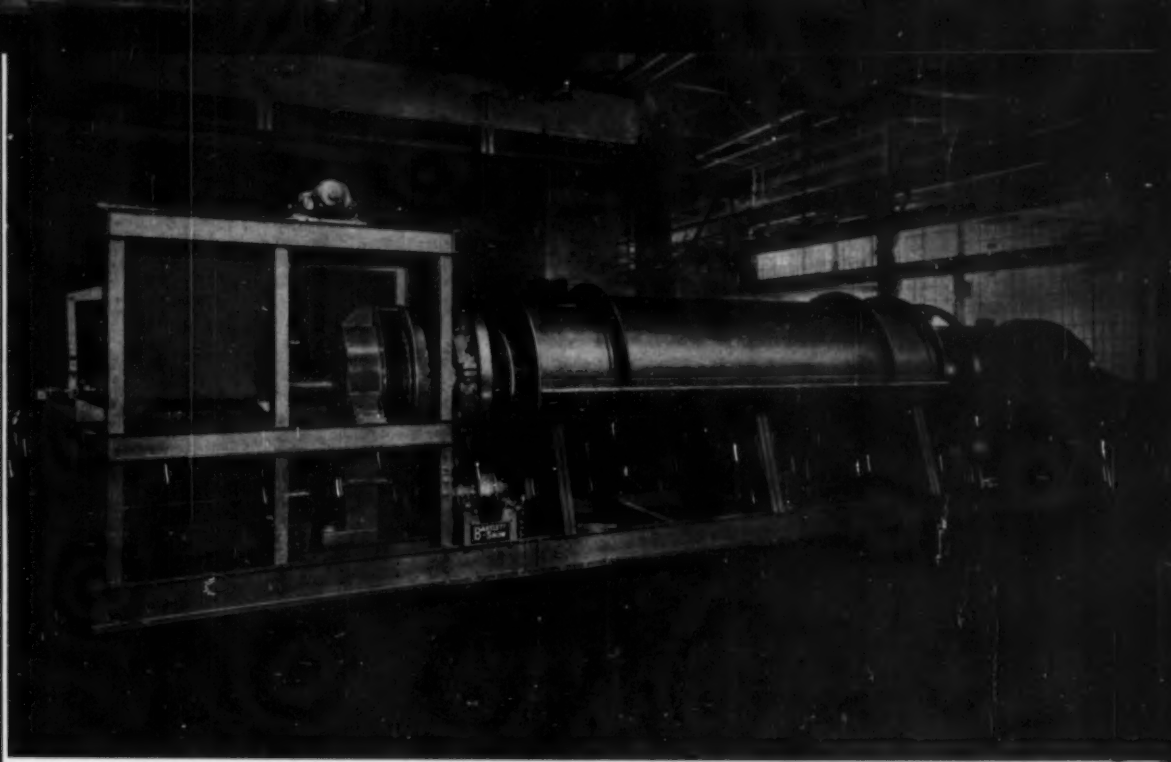
uses
special
atmosphere
if
desired

● These units permit materials to be processed continuously at temperatures from 900° F to 2100° F in a reducing, oxidizing or neutral atmosphere, cooled, and discharged at 200° F or lower. The chrome nickel alloy tube can be lined if desired, to permit processing without bringing the material into contact with metal at elevated temperatures. Feed hopper, variable feeder, seals and breechings are all supported on a single frame to assure proper alignment and efficient trouble-free operation. Our complete laboratory and experimental facilities enable us to determine accurately the time cycle, temperature, pitch, rate of feed, special atmosphere and all other conditions needed to produce a given result, before the production unit is designed or built. Let us work with you on your next job.

DESIGNERS ENGINEERS **BARTLETT B-SNOW** CLEVELAND 5, OHIO FABRICATORS ERECTORS

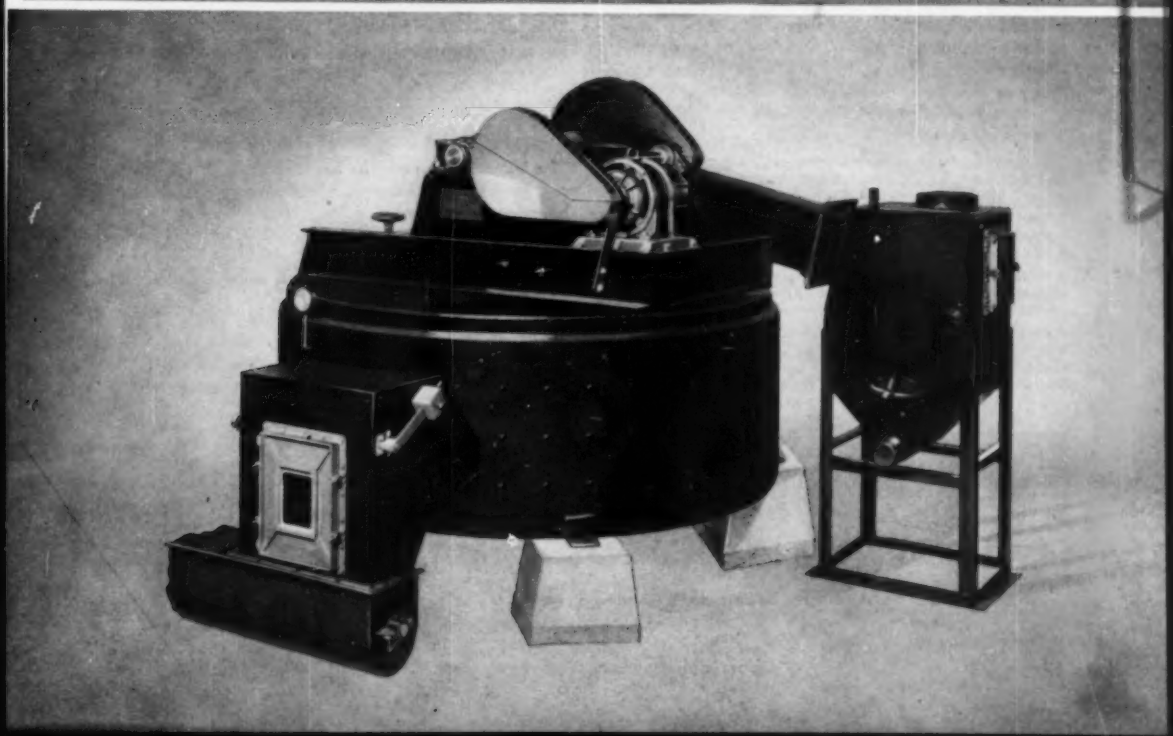
Dryers • Coolers • Calciners • Kilns

"Builders of Equipment for People You Know"



Above: Continuous Indirect Heat Special Atmosphere Calciner with High Temperature Cast Alloy Tube Showing Feed Hopper, Screw Feeder, and Cooling Section.

Below: Steam Jacketed Batch Dryer Showing Dustless Discharge to Screw Conveyor and Chamber Where Vapors Are Condensed and Fines Re-claimed.



HOW MUCH DO FILTER

...and what can you *do* about it?

Have you ever thoroughly investigated both the direct and indirect cost of filter cloths in your plant? If not, the chances are you will be surprised to find that annual cloth replacement and maintenance cost alone runs from $1.00 to $4.00 per square foot of press area per year, depending on the utilization of your press, the product and the type of fabric you use. Other costs associated with use of cloths, such as the labor for scraping, handling, washing; breaking and redressing the press; and purchasing time expended in obtaining the cloth you need when you need it will probably be even greater, even if not as easily pinned down.

Here are three immediate reasons why you should consider switching to modern high-speed Niagara pressure leaf filters:

1. Niagara Filters require no filter cloths. Accurate case histories in our files show that some plants amortize their Niagara filters in a few years on this saving alone.

2. Niagara Filters require less labor. When you eliminate filter cloths, you eliminate the back-breaking and costly labor that goes with them. With Niagaras you get a quick, easy, clean operation that takes only a few minutes for one man between cycles.

3. Niagara Filters provide greater utilization. Reduced down time means more production time, which means higher production at your filter station. The filter works for you more hours per day—gives you many more gallons throughput with less installed filter area.

By switching to Niagaras, many press users have realized overall savings that amortize the cost of the new filters in months. We can show you detailed case histories from our files presenting the economic soundness of replacing existing filter presses with Niagara filters.

Entirely aside from savings, here are eight sound reasons for installing Niagara filters:

1. Higher flow rates on an equal area basis. Niagaras normally give flow rates 2 to 5 times greater than conventional cloth covered filters.

2. Sparkling filtrate clarity. Positive removal of solids to practically any degree of clarity you desire. In sanitary applications, 0-0 bacteria count can usually be secured in one filtration.

3. No leakage. Fully enclosed, pressure-tight construction eliminates drippage and fumes. Ideal for handling flammable, explosive, toxic, volatile, or highly obnoxious liquors.

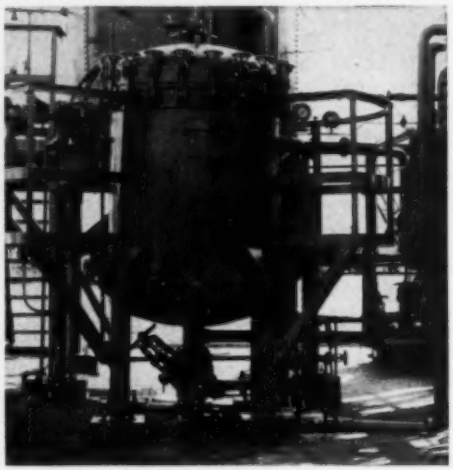
4. Wide capacity range. Sizes range from 20 to 950 square feet of filter area, with average capacity of 10 to 425 G.P.M. in one compact unit. (Even larger areas are available in the new horizontal filter shown at right on the opposite page.)

5. One-man operation and cleaning. Single or multiple units can be operated and cleaned easily by one man. The entire leaf battery is accessible for easy cleaning.

6. Corrosion-resistance. The pressure leaf filter can more cheaply and readily be constructed of stainless steel, nickel, monel and other corrosion-resistant materials.

7. Jacketed construction. Niagaras can readily be supplied with steam jackets or special insulation.

8. Excellent cake-washing characteristics. Nearly true displacement washing is obtainable.

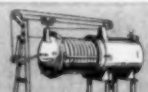


THIS NIAGARA FILTER, in large petrochemical plant, removes iron sulfide particles from solutizer solution.

HOW THE MODERN NIAGARA PRESSURE LEAF FILTER WORKS

The leaves, which are the heart of these filters, consist of double faced rectangular screen assemblies bounded by a tubular drainage frame leading to an outlet nozzle. The unfiltered liquid is pumped into the closed pressure filter tank in which the leaves are placed, and is forced through the fine mesh screen on which the filter cake is formed by the solids in the liquid. Only the clear liquid reaches the inside of the leaves, flowing through the coarse center drainage wire, to the tubular frames and out through the leaf nozzles to the manifold. When the designated batch

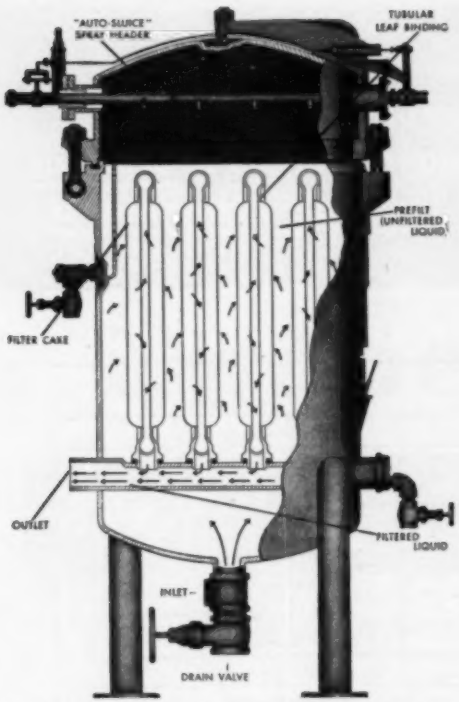
Niagara Filter CORPORATION



HORIZONTAL FILTERS for non-aqueous liquids and high solids, and cake recovery applications.

IN EUROPE—NIAGARA FILTERS EUROPE, 36 Leidsegracht, Amsterdam-C, Holland

CLOTHS COST YOU?



has been completely filtered, or when the cake has nearly filled the space between the leaves, the filter is emptied and the filter cake is sluiced from the leaves with a hose or with automatic high pressure sprays. Sluicing is done without removing any parts from the filter. As a rule, the filter is ready to go to work again in 15 minutes to 1 hour, depending on its size.

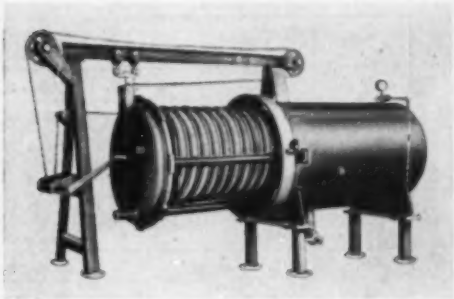
Reason for High Flow Rates

The rigid metal screens do not "give" under pressure —cannot obstruct flow channels in the drainage member as does sagging cotton cloth. Also, the filtrate drains by gravity as well as pressure. This combination of rigid metal leaves, plus bottom drainage, produces flow rates 2 to 5 times those of conventional filter presses.

There are no moving parts during filtration. This simple construction means lower maintenance costs, as any Niagara user will verify. Niagara filters are easy to keep clean and keep in operation.

Niagara's Five Helpful Filtration Services:

1. **Nation-wide field service.** Capable representatives in 24 cities.
2. **Complete testing facilities** help determine your requirements exactly.
3. **Pilot filter rental** enables you to "preview" Niagara performance in your plant, at low cost.
4. **Custom engineering.** A single filter or a complete system, designed for your exact needs.
5. **Installation and startup** are supervised by Niagara engineers, always on call.



NIAGARA'S NEW STYLE H* FILTER

for applications involving high per cents of solids

1. Gives 2-5 times the flow rates.
2. Cuts cleaning time to minutes.
3. Eliminates all cloth costs.

This new Niagara filter answers the need for a filter which can quickly discharge large quantities of semi-dry cakes. A variation of the standard Niagara design, it still retains all the basic advantages of Niagara vertical pressure leaf filters.

A retractable carriage permits all leaves to be withdrawn at once for rapid cleaning. One man can easily discharge as much as 150 cu. ft. of cake in a matter of minutes.

A new closure design, the Q/O* (quick-opening) cover, permits faster, easier opening and closing than ever before in a filter of this size.

The Style H* filter is ideal for filtration where high percentages of solids must be removed or where solids must be saved. It is also recommended for all standard liquid clarification where low headroom or other special reasons make its horizontal construction preferable to the vertical pressure leaf filter.

*Trade Mark Patent Applied For

NIAGARA FILTER CORP., 3881 Main St., Buffalo 14, N. Y.

Please send me ☐ General literature; ☐ Data on horizontal filters; ☐ Data on pilot filter rental service

Name_____

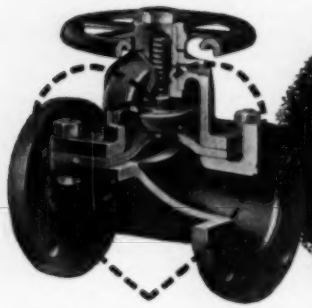
Title_____

Company_____

Address_____

City_____ Zone_____ State_____

for the heart of the Saunders Patent Valve . . .



Hills-McCanna offers a complete selection of diaphragm materials to best suit your individual requirements

Code Number	Base	Stock Type	Service Quality
R-1	Rubber	Carbon Black	Acid/Alkaline, Heat Resistant
R-2	Rubber	Non-Carbon Black	High Acid/Alkaline Resistant
R-3	Rubber	Carbon Black	Non-Fat Food Service
R-4	Rubber	Carbon Black	Special Non-Contaminating
R-5	Rubber	Non-Carbon Black	Acid/Alkaline, Abrasion Resistant
N-1	Neoprene	Carbon Black	Acid/Alkaline/Oil/Heat Resistant
N-2	Neoprene	Carbon Black	Fat Food Service, Non-Contaminating
N-3	Neoprene	White	Special Non-Contaminating
H-1	Hycar	Carbon Black	Acid/Oil/Heat Resistant
K-1	Butyl	Carbon Black	Acid/Heat Resistant
T-1	Tygon	Carbon Black	Acid Resistant
C-3	Compar	Carbon Black	Solvent Resistant
L-1	Special Polyethylene	White	Acid Resistant (66° Be Sulfuric)
M-1-25	Kel-F	Non-Carbon Black	High Acid/Alkaline Resistant

IN over 15 years of supplying Saunders Patent Diaphragm Valves to the processing industries, we have developed an extensive background of experience in the recommendation of the proper diaphragm material to meet a given set of conditions. This experience proves that only with diaphragms especially selected for your needs can you get the *best* service from your diaphragm valves. The wide range of diaphragm materials and their basic characteristics are shown in the table above. Each of these has advantages and limitations—no one is a cure-all—and the secret of successful selection of the right diaphragm is a thorough knowledge of these advantages and limitations.

Here at Hills-McCanna, recorded in the service records, is the experience that has resulted from valving over 2500 substances. This data is constantly being brought up to date to take into consideration the development of new diaphragm materials such as polyethylene and Kel-F. To any user of Hills-McCanna Valves, this record assures you of having the knowledge gained from thousands of other installations working for you.

Whatever your valving requirements, if they involve handling corrosive substances, slurries, semi-solids or other hard-to-handle fluids, we would welcome the opportunity to go over your needs with you. Hills-McCanna Diaphragm Valves are available in sizes from ⅜" to 14" handwheel or lever operated or arranged for automatic or remote operation. Choice of 14 diaphragm materials, 48 body materials. Write for descriptive literature. HILLS-McCANNA CO., 3025 N. Western Ave., Chicago 18, Illinois.

HILLS-McCANNA

saunders patent

diaphragm valves

Also manufacturers of Proportioning Pumps
Force Feed Lubricators • Magnesium Alloy Castings

Producers of foods, condiments, drugs and toiletries, detergent mixtures, insecticides, molding powders, heavy and fine hygroscopic chemicals, etc., etc.

Keep 'em Flowing

WITH

Magnesol*

THE *EFFECTIVE* FLOW-PROMOTER AND ANTI-CAKING AGENT

If your powdered, flake, or granular material now picks up moisture, cakes or agglomerates during shipping, storage, processing or use, MAGNESOL BRAND magnesium silicate may be just the flow promoter and anti-caking agent you need.

MAGNESOL is an adsorptive, synthetic magnesium silicate with a combination of unique physical and chemical properties that have produced unexpectedly good results in many diverse applications.

Its finely-divided structure forms an intimate, "slippy" coating on the protected powdered material. Its prolonged mildly desiccant activity lengthens the "shelf life" of packaged goods and prevents agglomeration of bag and bulk products.

Being a synthetic inorganic made under close chemical control, MAGNESOL has dependably uniform properties. High effectiveness in small quantities and modest price make the cost of using MAGNESOL nominal.

Successful large scale commercial applications indicate that it can be worth-while for you to explore the possibilities of MAGNESOL open-mindedly. We invite you to act upon the offer on the right.

SEND FOR TECHNICAL DATA AND TEST SAMPLE

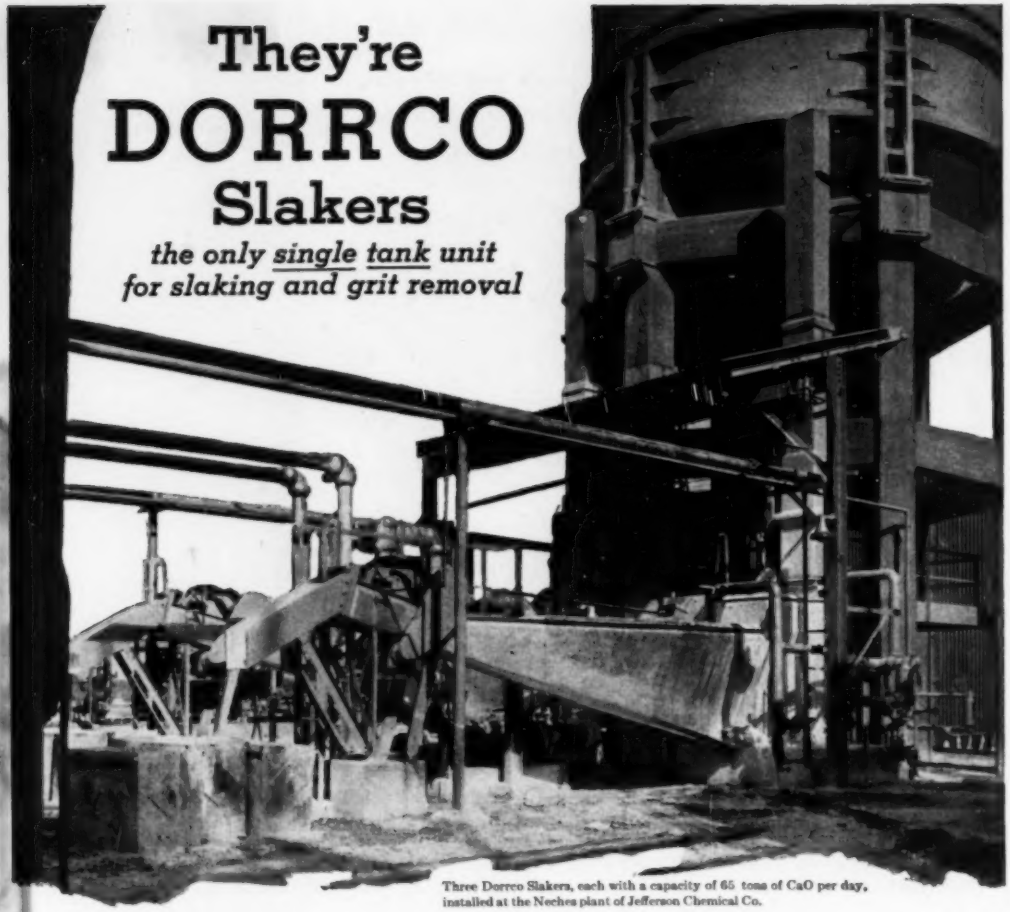
Kindly describe your problem to our Technical Service Division and obtain maximum benefit from our experience.

WESTVACO CHEMICAL DIVISION
FOOD MACHINERY AND CHEMICAL CORPORATION
161 EAST 42nd STREET, NEW YORK 17, N. Y.
CHICAGO, ILL. • CLEVELAND, OHIO • CINCINNATI, OHIO • CHARLOTTE, N. C.
ST. LOUIS, MO. • POCATELLO, IDAHO • LOS ANGELES, CALIF. • NEWARK, CALIF.

**MAGNESOL is the registered trade mark of Food Machinery and Chemical Corporation for its brand of magnesium silicate adsorptive powder.*

They're DORRCO Slakers

the only single tank unit for slaking and grit removal



Three Dorrco Slakers, each with a capacity of 65 tons of CaO per day, installed at the Neches plant of Jefferson Chemical Co.

To simplify your slaking operations, get to know the Dorrco Slaker. It is a neat and compact unit that provides safe and clean operation. There is a size to meet every need . . . from 5 to 200 tons of CaO per day.

Here is a quick look at some of the advantages the modern Dorrco Slaker gives you —

Large unit capacity because mechanism and tank design produces rapid hydration.

Quick installation at low cost . . . your Dorrco Slaker is shipped almost completely assembled, requires no field welding, no costly piping installation.

Low maintenance costs . . . because all bearings are above solution and 1" thick white iron liners in the slaking compartment are designed for quick and inexpensive replacement.

Bulletin No. 7281 gives you more information about the Dorrco Slaker, its compactness, its simplicity and its durability. A copy of Bulletin No. 7281 is yours for the asking. Write for your copy today. THE DORR COMPANY, BARRY PLACE, STAMFORD, CONN.

Better tools TODAY to meet tomorrow's demand

DORRCO

DORR

WORLD - WIDE RESEARCH • ENGINEERING • EQUIPMENT

THE DORR COMPANY • ENGINEERS • STAMFORD, CONN.

Offices, Associated Companies or Representatives in principal cities of the world.

take a
CLOSER LOOK
at

OXIDATION

Oxidation is one of the simplest yet most frequently-encountered forms of corrosion affecting the service life of steel tubes in high-temperature applications. When tubes are exposed to elevated temperatures for extended periods of time, scale will form of sufficient thickness to flake off, causing progressive loss of metal. Resistance to oxidation, or scaling, is therefore an important consideration in determining the suitability of tubes for severe temperature conditions.

Chromium is the most effective alloying element for providing oxidation resistance in steel tubes. It forms a tight surface layer of chrome-rich oxide which retards inward oxygen diffusion and protects the underlying metal from attack. The amount of chromium required for utmost freedom from excessive scaling is generally in proportion to the temperature conditions to which the tubes will be subjected. Under certain conditions, additional oxidation resistance may be provided by adding small amounts of silicon, titanium, or aluminum.

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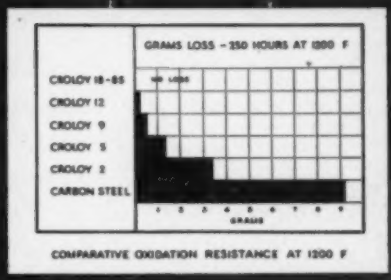
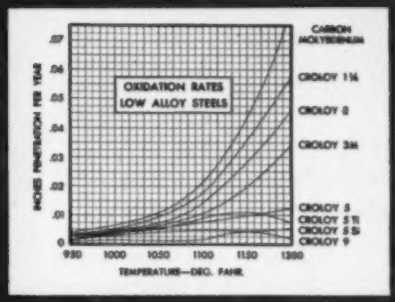
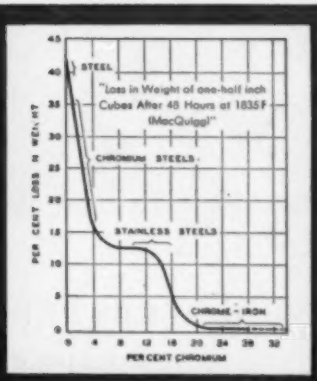


COMPARATIVE OXIDATION RESISTANCE AT 1200 F

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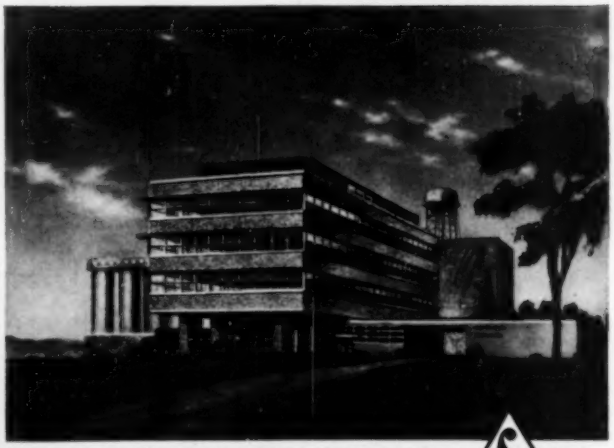

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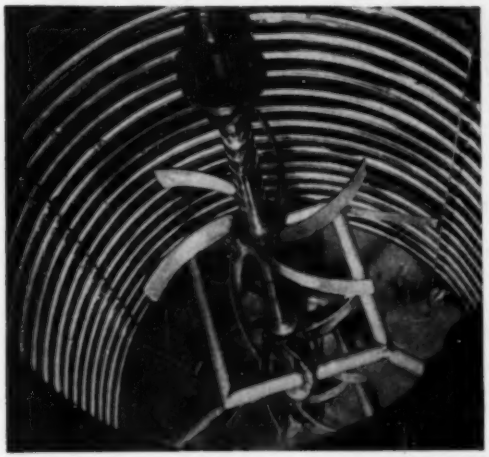

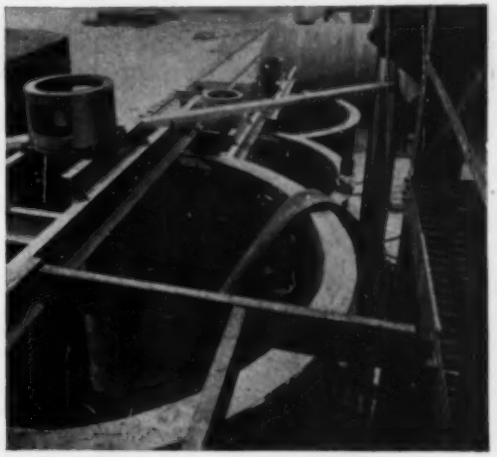

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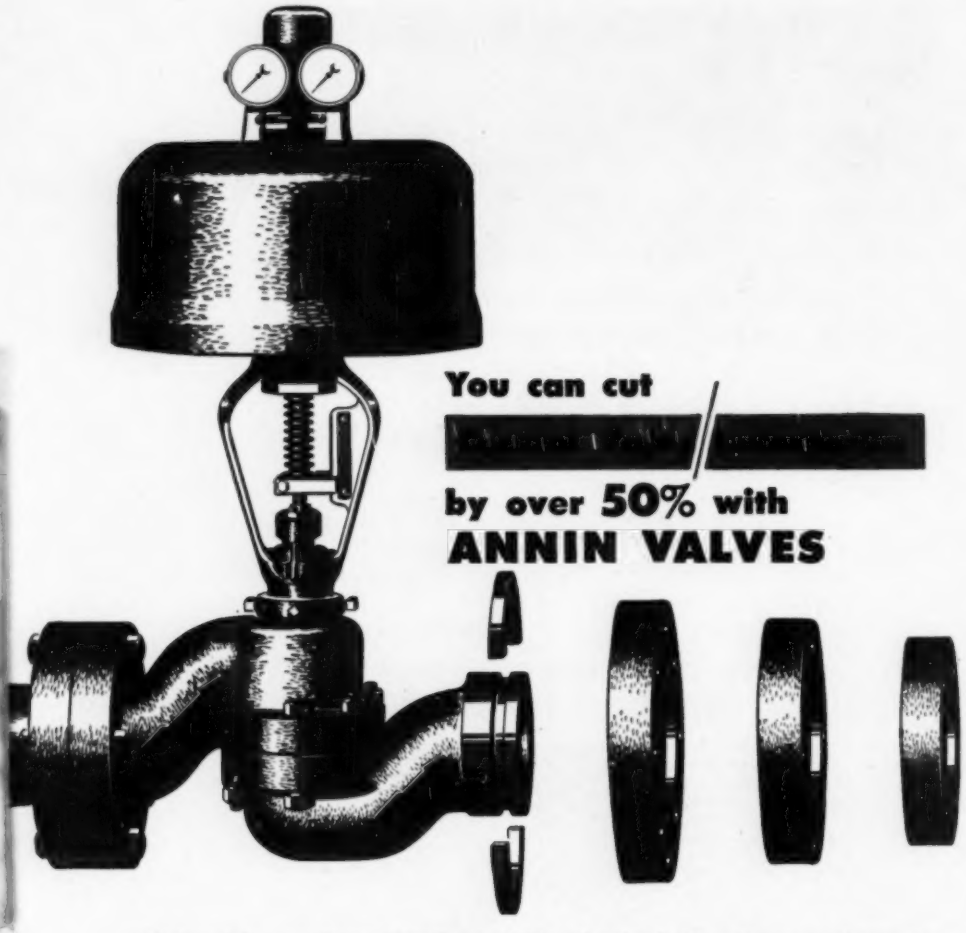

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SYSTEM	OVER-ALL PLATE EFFICIENCY		PRESSURE DROP/PLATE	
Benzene; Carbon-Tetrachloride	Vapor Velocity (ft/sec)	% Efficiency	Vapor Velocity (ft/sec)	In. of liquid at boiling pt., for static seal* of ¾ in.
	0.3	52		
	0.5	65	0.1	.8
	0.6	63	0.3	1.1
			0.5	1.3
Methyl-cyclohexane; Toluene	0.3	85		
	0.5	82		
	0.6	80		

*Static seal is distance from top of dot to top of downcomer.

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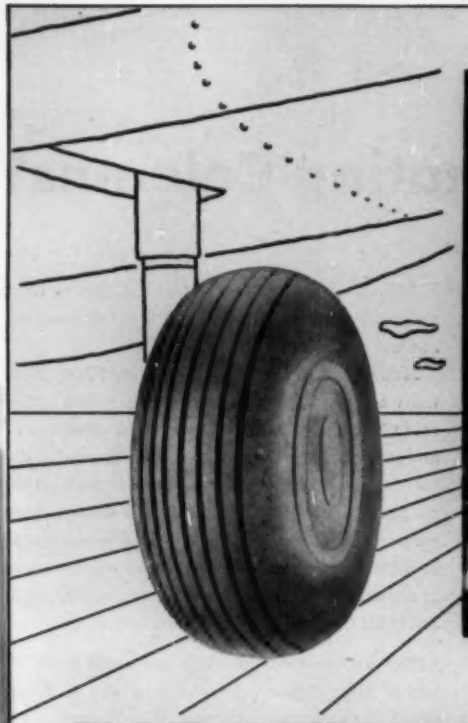

FORTUNATE ACCIDENT

In 1839 rubber wasn't much use. It melted and oozed in hot weather. In cold it stiffened and cracked. To remedy these failings, Charles Goodyear worked ardently but unsuccessfully. Yet he kept on. And the final solution of the problem came by accident when onto a hot stove Goodyear spilled a mixture of latex and Sulphur. This was the birth of vulcanization.

In the years since then, Sulphur has contributed further to rubber's versatility. By varying the proportion of Sulphur in the vulcanization mix, the properties of the rubber are changed — ranging from the battery case's rigidity to the rubber band's flexibility. And when supplies of natural rubber were cut off by war, Sulphur in various forms was found to be a most important element also in the production of synthetic rubbers.

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OPINION AND COMMENT

THOUGHT FOR FOOD

IN HIS essays on population, the British economist, Malthus, advanced the proposition that population tends to increase faster than food supply and argued that attainment of a balance depends on war, pestilence and poverty in keeping down population.

The teachings of Malthus are filled with errors. First of all, he failed to realize that every man born can be a producer as well as a consumer of food. He failed also to anticipate the ability of an unfettered scientific society to increase its food supply to any necessary extent. His argument is in error because the size of families tends to decrease not increase as living standards are raised. Finally, scientific developments have done so much to secure longevity and reduce infant mortality, that war, genocide and famines can no longer be counted on to reduce population.

The gloomy teachings of Malthus are unfortunate because they have constituted the scripture quoted by indifferent governments to excuse the impoverished condition of large segments of population. On the constructive side, however, the Malthusian philosophy now provides a challenge to agricultural scientists, and chemists to demonstrate that Malthus' conclusions are as untenable as his supporting arguments.

The job of planning a supply of food commensurate with world needs is both difficult and complex. According to N. E. Dodd, director-general of the Food and Agriculture Organization of the United Nations, success will depend as much on statesmanship, organization and international cooperation as on science and technology.

In regions where more than half the world's people live, agriculture is largely conducted with inadequate equipment, and scanty use of fertilizers and pesticides. Illiteracy is high, agricultural and other resources are poorly developed, and farmers are held down often by heavy taxes and rents. Considering that a basic cause of world discord is hunger, anything we can do to stimulate and achieve increased food production in deficit areas will be a contribution to the realization of a permanent peace.

From the viewpoint of the chemical engineer, the food problem can be analyzed in accordance with familiar concepts.

1. Is the problem soluble?
2. Can a favorable equilibrium between soil resources and population be obtained?
3. Can food production be catalyzed?
4. Importance of agronomic, entomological, social and institutional factors in securing a balance between population and adequate food supplies.

There is overwhelming technological evidence that "the world can feed itself if it has the will to do so." Peoples of many nations now enjoy a balanced and nutritious diet. Food is one of the best indices of living standards, which have a great effect on productivity. In agricultural, industrial, or mining pursuits, the United States worker excels labor in lands where a deficient diet prevails. Obviously factors other than nutrition are involved, but it is clear that unless undernourished nations utilize the food production experience of successful nations, the poorly fed will be worse off, and the well-fed will be better off in the years ahead.

Nearly all the good land in temperate regions is occupied, and with respect to the Western Hemisphere and Western Europe, the nations are well fed. The ill-fed countries are mainly those of Asia and much of Africa. Although crop land can be expanded in the temperate zone, the great areas of undeveloped soil are in the tropics and great tropical islands. Development of such new areas, which could provide a billion more acres of productive land, may involve such matters as clearance, sanitation and industrialization.

A more promising picture lies in the application of technology and the extensive use of chemicals to obtain increased yields on available acreage. Unfortunately, this cannot be done quickly, but once this is done, there is reason for confidence even though economic, industrial, and institutional problems must still be managed.

In the United States, financial incentives in the form of price supports are sufficient to catalyze the production of an exportable surplus of foods and fibers. During the past decade we have obtained an average per acre increase in yield of about 100 per cent on potatoes, 50 per cent on corn and 25 per cent on soybeans and cotton.

The major problem in organizing for food sufficiency in deficit areas is to catalyze an overwhelming desire in these less fortunate people for self-respect, self-help and self-determination. To paraphrase an old adage, the task is not to make them drink but to create an overpowering thirst.

The business of producing an abundance of food in the United States is relatively easy because of the work of plant breeders in developing better varieties, of the agronomist in improving farm practices and of the entomologist and plant pathologist in protecting crops against insects and diseases. In support of these workers, we have a large and rapidly growing agricultural chemical industry which supplies plant nutrients, pesticides, herbicides, defoliants, vaccines, medicinals and other chemicals which are essential to efficient and profitable farm operations.

During recent years, United States farmers realized a return of from four to eight dollars for each dollar invested in fertilizers. To ensure success in its future efforts to provide an ample food supply, the U. S. Department of Agriculture is now promoting a 60 per cent increase (from 4.2 to 7.4 million tons) of plant foods during the next five years.

American farmers know also the advantages of investing in pesticides. From the viewpoint of world food supplies, pesticides may spell the difference between feast or famine. This year, the domestic chemical industry will produce more than 360 million pounds of chlorinated insecticides (DDT, BHC, Toxaphene, etc.) alone. About 20 per cent will be exported on government programs and through commercial channels.

Two new chemical discoveries may also play vital roles in providing food for millions. The first is krilium, a hydrophylic and airophylic soil stabilizer, which has demonstrated its ability to rejuvenate soils of high clay content. The second is the recently reported ion exchange method of treating sea water whereby an economic and potentially inexhaustible supply of water for soil irrigation, particularly in food deficit regions may be provided. Other discoveries as well as countless developments now in the experimental stage should, in the years ahead, continue to show that the world can feed itself if it has the will to do so.

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Composed of skillfully modified polyvinyl resins, TYGON — as calendered or press polished sheet; as extruded tubing, solid cord, or channel; as molded goods; or, as a coating — represents the maximum possible in chemical resistance and physical properties. Naturally, the properties of TYGON vary according to the form in which it is used. But in every case, long experience and careful compounding assure the optimum. Proper application is the only needed step to completely satisfactory service with hydrochloric acid or other corrosive chemicals.

As a calendered or pressed polished sheet, TYGON is resistant to hydrochloric acid in any concentration up to 35% by weight and at temperatures as high as 165°-170° F. When subject only to the fumes of the acid, service temperatures can be raised to 200° F. Prolonged contact with mixtures of hydrochloric and other acids is not advised without the previous counsel of U.S. Stoneware engineers. In sheet form, TYGON is used primarily to line tanks, vats, drums, hoppers, bins, fume hoods and fume ducts. Substantial quantities are also cut into gaskets, washers, and diaphragms for use as long lasting, resilient seals or separators in pumps, valves, filters, piping, and a wide variety of process equipment.

As extruded tubing, cord, or channel, TYGON resists hydrochloric acid and its fumes in all industrial concentrations and at temperatures ranging up to 200° F. Lengthy exposure to mixed acids is not recommended without qualified advice.

In extruded form, TYGON has a wide range of application. Most important, however, is its use as flexible tubing and piping in both the plant and laboratory. Long lasting, flexible and transparent, TYGON Tubing is great improvement over glass and other tubing in many complicated lab "set-ups." In the larger sizes, up to 2"ID, the high strength, light weight, and smooth surface of TYGON Tubing qualifies it for use as flexible piping in permanent or temporary acid transfer lines, as gas lines, as syphon hoses, as flexible connections, or as line desurgers. Where constant pressures of more than 40 psi are involved, particularly at elevated temperatures, braided jacket reinforcement is available and suggested.

Extruded cord and channel is generally used as gasketing, but also finds application as expansion jointing and as packing.

As molded goods, TYGON exhibits the same resistance to hydrochloric acid as its extruded form. Pressure and temperature limits vary according to size and design of the piece and the conditions of service, but usually are higher than those for the other forms.

Molded, TYGON takes the form of gaskets, grommets, washers, stoppers, closures, handles, bumpers, and special fittings. Where necessary, it can be reinforced with glass fibers for added strength.

As a coating, TYGON is available as a solvent type paint or as a plastisol. In either form, chemical resistance varies according to the thickness of the coat applied. Special consideration should be given to the limits of a thin film. In general, however, properly applied TYGON PAINT resists the fumes and spillage of hydrochloric acid in any concentration and at temperatures up to 200°F. The thicker coats of the plastisol (Tygoflex) are resistant at as high as 250°F.

As a paint, TYGON is used to protect all types of equipment, structural steel, walls, and ceilings. The number of coats to apply depends upon the conditions of service: a primer plus two topcoats is suggested for mild environments and a primer with no less than five top coats for severe exposures. TYGOFLEX finds use as a heavy duty coating and in the casting or "slush" molding of flexible parts and fittings. In coating work, it is applied by dipping or spraying on hot metal, and then fusing with heat.

TYGON, in any of its forms, is low cost insurance against the attack of not only hydrochloric acid and related chemicals, but a wide range of other acids, alkalies, oils, greases, and water. The different forms available and the range of mechanical, physical, and chemical properties they exhibit, permit the proper use of TYGON in many applications. Versatility and satisfaction in service is further assured by the custom engineering, compounding, and fabricating services available.

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In addition to TYGON in its various forms, we also manufacture a number of other materials capable of handling hydrochloric acid in any concentration and under all types of operating conditions. These products include chemical stoneware and porcelain, acid proof brick and cements, homogenous lead linings, and other organic linings and coatings.

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PREVENTIVE MAINTENANCE IN THE CHEMICAL INDUSTRY

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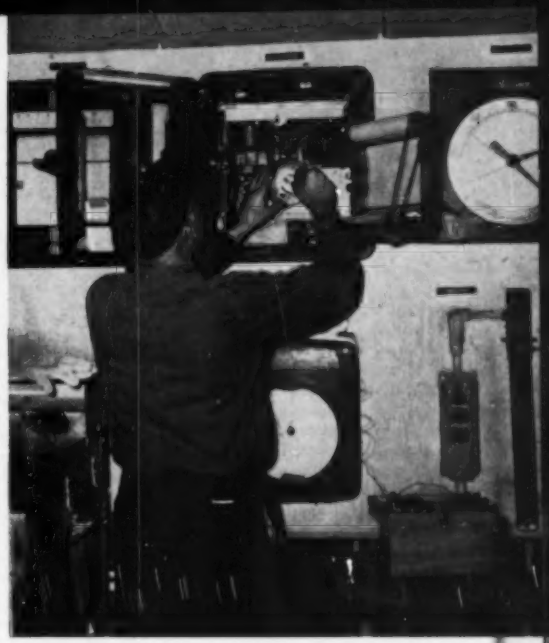

"Preventive maintenance is receiving increased attention as a means of reducing costs without the burden of increasing capital." Instrument maintenance experience shown in this article cut overtime in half.

THE development of any industry within a free economic system is normally accompanied by a steady increase in competition. The chemical industry is no exception. The steady increase in competition along with the increase in labor and material costs over the past few years has reduced the margin between manufacturing costs and sale prices of many of our established products. As the margin of profit has decreased, it has been necessary to place more and more emphasis on the reduction of manufacturing costs.

The reduction of maintenance costs in most chemical plants is a fertile field because too little emphasis has been placed on the scientific approach to maintenance work. New processes are thoroughly researched and pilot-planted. Production plants are thoroughly engineered to give efficient operation with logical and attractive arrangement of equipment at reasonable installation costs. However, comparatively little engineering planning has been given to the maintenance of the plants after they are in operation.

Improvement in yields to reduce raw material consumption and the introduction of labor saving devices are important factors in the reduction of manufacturing costs. However, savings in raw materials are limited by theoretical yields, and most labor saving improvements are accomplished at the expense of increased capital. The reduction of maintenance cost, on the other hand, has no theoretical limit and in many cases does not require additional capital.

Industry is now beginning to recognize the potentialities of reduced maintenance costs. An increasing number of talented engineers are being assigned to maintenance, and maintenance engineers are being elevated to higher positions of responsibility within plant organizations.

Preventive maintenance is receiving increased attention as a means of reducing costs without the burden of increased capital. The purpose of this paper is to define preventive maintenance and to discuss its application.

Preventive maintenance can best be defined by stating that there are two general systems of maintenance; one, "fix it after it breaks," and the other, "fix it before it breaks." Preventive maintenance is the system which provides for fixing it before it breaks. Most of us who operate our private automobiles without frequent trade-ins consider it economical to purchase new tires at some time prior to the expected failure of the old. This is a simple illustration of preventive maintenance.

Preventive maintenance is not a panacea, it will not eliminate all failures and it cannot be applied economically to all phases of maintenance. In general it should be applied to equipment and conditions where mechanical failure presents a personnel hazard, expensive down time, or excessive repair costs through damage to material other than the failing element. Applied under proper conditions, the advantages over conventional maintenance are:

Reduction of Personnel Hazards. Reference has been made to the replacement of tires on our private automobiles. The personnel hazard involved in a blow-out is brought to our attention in magazine advertisements. The reduction of this hazard by properly scheduled replacement of tires is obvious. The responsibility of all industry to eliminate human suffering establishes preventive maintenance as a must where personnel hazards are involved. State laws require its application to steam boilers, elevators and other specific classes of equipment.

Reduced Down Time. Have you ever experienced a flat tire on your way home from an afternoon of golf when your wife was waiting with a hot fish dinner? If you have, you probably found it a rather expensive down time. A set of new tires at the proper time might have eliminated the tire failure. In plant work the cost of down time usually can be determined specifically in dollars an hour, particularly with continuous operations.

Reduction of Direct Maintenance Costs. Again using the private automobile as an example, it is also possible that in due course a tire failure would result in an accident which would damage things other than the tire and this damage might include personal injury. Under these circumstances, we would be faced with repair costs far in excess of the cost of a new set of tires.

Discovery of Sources of High Maintenance costs. The discovery of sources of high maintenance costs, is not readily apparent and can best be illustrated by an actual case uncovered by a preventive maintenance program applied to centrifugal pumps within a chemical manufacturing plant. Soon after the program was inaugurated, the engineer in charge noticed that each report from one of the mechanics indicated that one pump was being packed at each scheduled inspection. Further investigation revealed that this pump was being packed at least once each 8-hour shift. A simple change in packing materials resulted in a normal operation of the pump in excess of 90 successive shifts without repacking. The preventive maintenance program laid the facts on the engineer's desk, and without it the pump would probably still require packing once during each 8-hour shift.

The question may be raised as to why it took a preventive maintenance program to uncover this condition. It certainly could have been noticed without the program, but the fact that it was not indicates the value of formalized preventive maintenance in the discovery of problems which can otherwise be overlooked. Preventive maintenance in this way supplements regular maintenance in discovering items of high or excessive maintenance requirements.

A well-organized plan for complete departmental shutdowns permitting preventive maintenance on a departmental basis is a maintenance engineer's dream. This is a common practice in the oil industry, but it can seldom be realized in a diversified chemical plant. Full advantage of the departmental shutdowns should always be taken, but a well-developed preventive maintenance program must normally follow a different approach. One logical approach is to base the program on specific classes of equipment on a plant-wide basis with close intra-departmental coordination being the key to releasing individual units of equipment as required. A program developed on this basis should include the following elements:

Scope. The success of any preventive maintenance programs depends first of all, upon the selection of the classes of equipment to which preventive maintenance can be applied. The selection is a large order for the maintenance engineer. The idea of preventive maintenance is not difficult to sell to production supervision and higher levels of management. In fact, it is a very attractive package when properly selected and wrapped; however, there are many items and operating conditions in any plant to which preventive maintenance cannot economically be applied. The maintenance engineer must be careful not to oversell the idea. In developing a program, it seems logical to start by selecting the class of equipment which will yield the desired results. A good starting point in most chemical manufacturing plants can be found in product scales or other weighing and measuring devices. Inaccurate weighing of finished goods and raw materials in process leads to losses both in customer relationships and in inventories. Centrifugal pumps is another item which will provide an ideal starting point for a preventive maintenance program. Only after going through the development of a preventive maintenance program for one or two classes of equipment, can the possibilities and limitations of preventive maintenance be evaluated with any degree of accuracy. From that point on, the programs should be developed on the basis of an economic study of each class of equipment.

Determination of Optimum Inspection Interval. The calculation of inspection intervals to be applied within a preventive maintenance program is a vital part in the effectiveness and economy of the program. Obviously, if the inspection interval is too short, unnecessary expenses will be incurred. Yet if the interval is too long, the number of breakdowns between inspection intervals will reduce the effectiveness of the program. In determining the optimum inspection interval, experience and clear thinking are the best tools available.

A Formal Maintenance Schedule. Any fully developed preventive maintenance program logically includes some system of schedules corresponding to the preselected inspection interval to provide for the "fixing before the breaking." This fact is so axiomatic that the terms preventive maintenance and scheduled maintenance have become synonymous. Ingenuity can be exercised in the development of the printed form on which the schedule is outlined. Simplicity and completeness should be given primary consideration.

Mechanics Report. A preventive or scheduled maintenance system can hardly be effective without a report from the worker. This report includes an indication of the relationship of actual performance to the schedule, and a description of the work performed. In most cases the maintenance schedule and the worker's report can be combined into one printed form.

An Engineered Maintenance Parts Program. A well-engineered maintenance parts program is essential to the success of any maintenance activity and it is practically futile to consider an extensive preventive maintenance program without the assistance of an engineered maintenance parts program. The program must include an engineering determination of the specific parts and quantities which are to be made available for each piece of equipment. The program should include consideration of inventory investments, sources of supply, interchangeability of parts, vulnerability of specific parts and importance to operations of each piece of equipment. A vital part of the program is involved in the identification, storage, and issue of the parts. A complete program must also provide adequate information to the mechanics through such media as maintenance parts manuals for specific pieces of equipment.

Analysis of Results. An analysis of results is essential in practically every field of engineering endeavor. In evaluating results, the selection of maintenance cost indices is very important. The perfect index would be one which evaluates all factors of the program without any outside variables. It is safe to state that there is no perfect maintenance cost index. In some cases, the object of the index may be to indicate changes in total maintenance costs; in others, reduction of down time may be the predominant factor with total maintenance cost a minor factor. A universal maintenance cost index is almost as remote as a universal chemical process.

The index used for a particular maintenance activity must be selected to fit the situation using available data and statistics in a manner similar to the selection of a chemical process where consideration is given to available equipment. The development of statistical data for a particular maintenance program may often be justified. Any index selected should be used with caution since accurate evaluation of all outside variables is seldom possible. The comparison of results based on a number of different indices is of value in drawing conclusions. A number of typical maintenance cost indices which are normally available are discussed briefly as follows:

Total Direct Maintenance Cost. If the total maintenance costs of the specific class of equipment can be isolated this is an important index. It will be affected by outside variables such as wage rates, parts costs, number of units, and severity of service. These variables can be evaluated fairly accurately when operations and products remain stable, but they become more difficult when production operations are not stable. The obvious shortcoming of this index is that it does not incorporate any evaluation of down time.

Ratio of Maintenance Costs to Pounds of Material Produced. This index is subject to the same variables as the direct maintenance cost. It is of little value in a plant wide study if there is a variety of products produced on intermittent or varied rates. It does incorporate an evaluation of down time.

Ratio of Maintenance Costs to Capital Investment. In general maintenance costs tend to increase with the age of an investment. This fact may introduce a variable difficult to evaluate when using this and most of the other available indices. When replacements continue to cost more than the original investment, as they have in recent years, the outside variables connected with this index present a real problem.

Relationship of Maintenance Costs to Electrical Power Consumption. A recently published formula relating maintenance costs to power consumption is a particularly interesting derivation. The formula, no doubt, has many valuable applications in studies of overall plant maintenance costs, but it would appear to have limitations when applied to specific classifications of equipment.

Application to Programs

Reference has been made to a preventive maintenance program applied to

W. E. Chandler, plant engineer of Monsanto Chemical Co., was graduated from Georgia School of Technology with B.S. degree in mechanical engineering in 1938. He spent two years in plant maintenance work at the Huntington (W. Va.) plant of American Car and Foundry, then one year at Purdue University, receiving an M.S. degree in mechanical engineering in 1941. He spent four years in the Service with 37 months overseas in theater communications, attaining the rank of major. Returning to civilian life in 1945 to start work as a maintenance engineer at the Nitro (W. Va.) plant of Monsanto, he advanced to superintendent of maintenance and construction in 1947, and to plant engineer in 1951.

centrifugal pumps. This particular program will be outlined to show how it was set up, and to demonstrate the results obtained. The plant in which the program was applied manufactures from 50 to 60 different products and employs approximately 800 total personnel. It is a medium sized plant, highly diversified, and the degree of modernization of the departments varies over a wide range.

There are approximately 270 centrifugal pumps in use, made by over twenty different manufacturers with numerous variations in types and models. The majority of the pumps are subject to intermittent operation twenty-four hours a day seven days a week. Prior to the decision to establish the preventive maintenance program the maintenance of the pumps had been done by any and all of some twenty-five sets of mechanics on a "fix it as you break it" basis.

It was obvious that a period of specialized training was required before the full benefits of the program could be obtained. Two mechanics and one helper were assigned to the specific and exclusive duty of pump maintenance in June, 1947. After eight months of training, the full preventive maintenance program was started in March, 1948.

Figure 1 is a copy of one page of the current schedule and is presented as a typical example. The form combines the schedule and the worker's report on the same sheet. From the chart, the inspection interval is indicated as two weeks. This interval was selected after a close study of the maintenance performed on a number of pumps prior to establishment of the program. This study indicated that maintenance was seldom required in intervals less than two weeks but that the calls for maintenance at intervals between three and four weeks were quite frequent. An inspection interval of two weeks appeared to be optimum.

The selection of an index by which results could be judged was studied carefully. Since the number of pumps in operation varied considerably from time to time, it seemed desirable to select an index which would compensate for this variation. It was assumed that the ratio of minor repair costs of the centrifugal pumps to the total plant minor repair costs would remain fairly constant as long as other maintenance procedures were not changed. On this basis, the index selected was the ratio of pump minor repair costs to the total plant minor repair costs expressed in percentage. Minor repairs represent individual repairs costing less than $150 in combined direct labor and material.

Figure 2 indicates the results obtained from the program at the end of 1949. It will be noted that pump maintenance represented 8.1% of the total minor repairs during the 18-month period prior to the specialized training period. It dropped to 7.2% for the period of specialized training and to 6.3% for the period of preventive maintenance. Expressed in more finite terms these figures indicate that the pump maintenance costs were reduced 11.1% by specialized maintenance and again 12.5% by preventive maintenance. The summary of results as outlined does not reflect the direct savings resulting from reduced down time and refer to direct maintenance costs only. The results, of course, must not be considered absolutely accurate since the basic index is subject to variation; however they are convincing enough to prove the merits of the program.

Figure 3 covers the same preventive maintenance program on centrifugal pumps using the total direct pump repair costs as an index. It is presented to show the necessity of evaluating the large outside variables when they are included in an index. The chart indicates an overall increase from $1,130 to $2,068 a month between general maintenance and preventive maintenance. The index includes the outside variables of wage rates, material costs and number of pumps in operation. The number of pumps increased 39% between the two points. Adjusting for this variable brings the original figure of $1,130 a month to $1,570. Wage rates increased 30% and material costs increased approximately 60%. Assuming an even split between labor and material the direct repair costs increased approximately 45%. Making a second adjustment for this combined variable brings the final adjusted figure to $2,276. Comparing the adjusted figure of $2,276 a month with the actual figure of $2,068, it is indicated that a saving of $208 a month has been realized. This saving represents about 9% decrease in cost which is slightly less than half the decrease indicated by the previous index. Like the previous index, this index makes no evaluation of down time.

Figure 4 shows the summary of results of the preventive program for instruments in which an entirely different index was used. In this case it was felt that the total monthly man-hours of overtime charged to instrument maintenance would be a good index, primarily because overtime data were available in this case where they were not available in the case of pumps. Furthermore direct cost of instrument maintenance was not available as it was with pumps. This index, unlike the one for pump maintenance, gives some evaluation of the decrease in down time due to the improved maintenance of the equipment involved. Note that in the twelve month period prior to the establishment of the preventive maintenance program, the average overtime per month was 56 man-hours compared

BLDG. NO.	DESCRIPTION	EQUIP. NO.	PKG. TYPE & SIZE	INSP'T. SCHED. DATE	REMARKS
46	DEMING	4-620	733- 3/8	2ND. WK. 4TH. WK.	O.K.
					O.K.
46	AM-HCM-5	4-653	733- 3/8	"	Ebl. 11-9
					O.K.
46	AM-HCM-5	4-593	733- 3/8	"	Ebl. 11-27
					O.K.
46	AM-HCM-5	4-655	733- 3/8	"	O.K.
					two bearings
46	DURCO 2	4-681	736- 3/8	"	O.K.
					O.K.
46	AC 1- 1/2	4-600		"	O.K.
					two shaft sleeves
46	25EL-3 MARLOW 2	4-691	SEAL	"	O.K.
					O.K.
46	NASH HYTOR	3-85	736- 1/2	"	Ebl. 11-2, 11-24
					out for repairs

Fig. 1. Pump maintenance schedule.

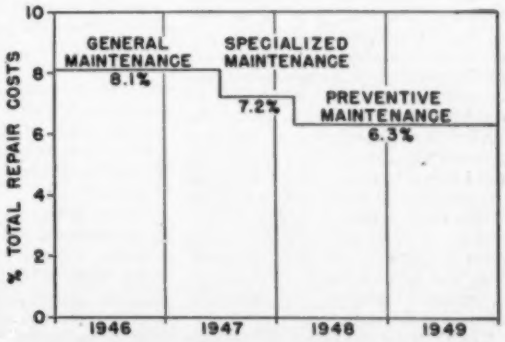

Fig. 2. Centrifugal pump maintenance.

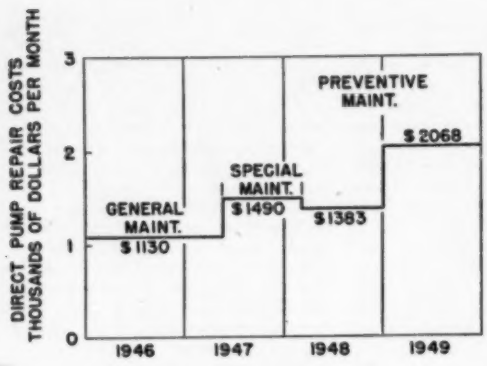

Fig. 3. Centrifugal pump maintenance.

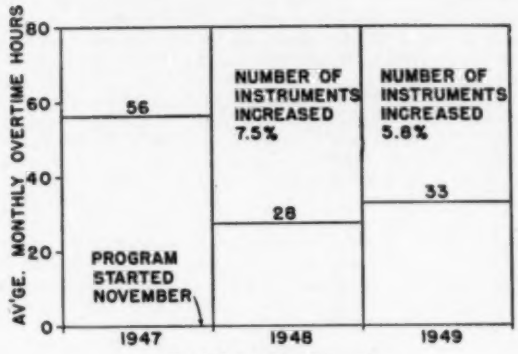

Fig. 4. Instrument maintenance.

to 28 during the next twelve month period, even though there was an increase of 7.5% in the number of instruments involved. The increase from 28 to 33 man-hours a month during the second year of the program is partially explained by an additional increase of 5.8% in the number of instruments. There was no change in the number of mechanics assigned to instrument maintenance throughout the period covered by the chart.

None of the three indices used in evaluating the two specific programs includes an evaluation of supervisory costs. However, after three years of operation with the two above programs, the supervision required to administer the maintenance of the equipment involved is estimated to have been reduced 50%. This reduction has enabled the engineers and foremen to devote more time to other fields of maintenance activity.

Additional classes of equipment covered by similar programs include centrifuges, autoclaves, weigh scales, sprinkler systems, and hoisting equipment.

The maintenance of all types of insulation throughout the plant has always been a problem. Early in the development of preventive maintenance programs this problem was viewed with particular interest. The point was finally reached where insulation failures did not require all of the available time of the mechanics and a preventive maintenance program was started. The plant was divided into a number of small areas and these designated areas arranged in sequence on a combined schedule and report form. The mechanics are being given a relatively free hand to decide upon and perform the work necessary to maintain properly the insulation throughout the plant.

The electrical equipment and systems within the plant are complex and heterogeneous in nature, presenting an interesting field for the maintenance engineer to apply his ingenuity in the development of a comprehensive, integrated and effective preventive maintenance program. At the present stage some few separate and specific programs are being executed on a semi-formal basis with the major job of formalization, expansion and integration yet to be done.

No discussion of chemical plant maintenance would be complete without mentioning paint and other protective coatings. As in the case of insulation, a certain level must be reached before a comprehensive preventive maintenance program can be expected to work. To reach that level the following must be done. New installations must be properly coated and maintained. Old installations must be reworked with adequate surface preparation and properly coated, then maintained. While this is being done, the remainder of the old installations must be given sufficient maintenance to hold them over until they can be properly taken care of or replaced. New developments in coatings and surface preparation materials and techniques will also play a part in reaching the goal. Once the desired level is reached a comprehensive preventive maintenance program should maintain the protective coatings during the intervals between complete resurfacing to the extent that the coated materials are fully protected.

In concluding, preventive maintenance is a method of maintenance, simple in concept, commonly practiced, which when organized on a formal basis and properly applied becomes a powerful tool in reducing manufacturing costs without the burden of additional capital investment.

Discussion

Herbert Johnson (Shawinigan Chemicals, Ltd., Shawinigan Falls, Canada): The statement was made that the cost of down time could usually be arrived at and that this is an important factor in the economics of maintenance. How can down-time costs actually be arrived at?

W. E. Chandler: Consideration must be given to the sales picture of the products which are being manufactured. If every pound of material which can be produced is being sold and if sales are being lost on every pound of material which is not produced, the calculation of down-time costs can readily be calculated from the loss of profits. If it is not possible to sell all material which can be produced within a department, it becomes more difficult to calculate the cost of down time. By studying each department individually a fairly accurate evaluation of down-time costs can be made.

James W. Casten (Buflovak Equipment Corp., Buffalo, New York): Should design drawings be sent to the maintenance engineer?

W. E. Chandler: Yes. Someone who is responsible for maintenance should review all drawings issued by the design department.

John V. Kuivinen (Parke, Davis & Co., Detroit, Mich.): How should the inspectors involved in a preventive program be selected?

W. E. Chandler: In general the inspectors should be men who can actually perform maintenance work. From this, it follows that they will normally be from the hourly group. In setting up a new preventive maintenance program it normally will be necessary for an engineer to train the foreman and mechanics before the mechanics assume their full responsibility.

DISPERSION FROM SHORT STACKS

C. A. GOSLINE

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IN recent years, and especially since World War II, there has been a growing tendency for cities to control discharges of smoke, soot, vapor, fumes, and obnoxious gases. Partly because of this, but mostly because of public sentiment, industry has increased its efforts and sometimes has taken drastic steps, to correct existing and to avoid new air pollution problems. Typical examples of these problems and solutions have been discussed by the writer et al. (*8-11*). In spite of the widespread use of stacks for disposal of materials that could not be collected for physical or economic reasons, the design and operation of stack-disposal systems has been largely based on previous experience or rule-of-thumb methods. The outstanding theoretical treatments of dispersion from a continuous point source were virtually unverified by actual tests.

Theory of Dispersion from Stacks. It is generally realized that the attainable dispersion of stack effluents is markedly affected by weather factors as well as nonweather factors.

The formulas that have been developed attempt to define the shape of the atmospheric "cone" in which the stack gases are dispersed. This cone is ventilated at a constant rate according to the velocity of the wind. The cone's shape and volume are determined by the stack height, the length of dispersion along the longitudinal axis (the distance from the stack), the height of dispersion along the vertical axis, and the width of the dispersion along the axis normal to the direction of flow. Variations in deviations from a true cone are compensated for by different exponents and power functions. In the formulas that have been developed, the time-average concentration at ground level varies directly as the emission rate of the material; inversely as the wind speed; inversely as the distance raised to a power of 1.5 to 2.0; and inversely as the exponent of the ratio of stack height to distance, plus the ratio of distance to one side of the axis of flow to distance downwind. The two main working formulas are described more specifically as follows:

Bosanquet's Theory. One of the first workable formulas was developed in England (*2*). On the basic assumption that the dispersion of the effluents is uniform about an axis, the following physico-mathematical relation was derived from phenomena of eddy diffusion.

$$Co = \frac{M}{\sqrt{2\pi pqVX^3}}\, e^{-a}$$

where

$$a = \left(\frac{h}{pX} + \frac{y^2}{2q^2X^2}\right) \qquad (1)$$

and also where

- Co = fractional concentration (by volume) of stack gas in air at ground level, dimensionless
- M = volume rate of emission of stack gas, cu.ft./min.
- V = wind speed, ft./min.
- X = distance from stack, ft.
- h = stack height, ft.
- p = vertical diffusion coefficient, 0.05
- q = horizontal diffusion coefficient. 0.08
- y = distance to one side of longitudinal axis of stack gas cloud, ft. (y is always zero some place downwind)

The coefficients p and q vary with different weather conditions, and are low when there is little turbulence and high when there is considerable turbulence. As found from observations made by Dobson (*5*), Richardson (*12*) and others, the values of p and q average 0.05 and 0.08, respectively, but may vary by threefold (*2, 5, 12, 13*). Due to their variations, Cp will vary, as will the distance at which Co is a maximum. Using Formula (1) this variation has been plotted in Figures 1*A*, 1*B* and 1*C* for constant ratios of stack height to distance; a value of 10 cu.ft./min. was assigned to M; a wind speed of 100 ft./min. was assumed. From Figures 1*A*, 1*B* and 1*C*, Figure 2 was plotted; it shows how the former may be used in the analysis of a problem.

Sutton's Theory. More recently formulas have been published (*14, 15*) applying to the distribution of pollution discharged from chimneys. The main formula is

$$X = \frac{2Q}{\pi C_y C_z u x^{2-n}}\, e^{-a}$$

where

$$a = \frac{1}{x^{2-n}}\left(\frac{y^2}{C_y^2} + \frac{z^2}{C_z^2}\right) \qquad (2)$$

and also where

- X = ground-level concentration of smoke, Q, g./cu.m.
- u = mean wind velocity, meters/sec.
- x = distance from the source, meters
- z = elevation of discharge point, meters
- y = distance normal to main axis of flow, meters
- Q = rate of emission of material, g./sec.
- C_y = diffusion coefficient along y axis, meters$^{n/2}$
- C_z = diffusion coefficient along z axis, meters$^{n/2}$
- n = turbulence index, dimensionless, a number between 0 and 1

The value of n is reported to be 0.20 for a large decrease of temperature with height, 0.25 for average conditions, and 0.33 to 0.50 for increases of temperature with height. The value X is sensitive to n. Values of C_y and C_z are tabulated in Table A.

Church's Theory. In November, 1949, "Dilution of Waste Stack Gases in the Atmosphere" was published (*4*). Church treats the stack gases as a unit and then describes their dispersion by means of dilution factors. A dilution factor of 500 means that the stack gases were diluted 500 times by the atmosphere between the discharge point and the point in question. Thus, a stack discharge containing 0.2% SO_2 by volume would have a concentration of 0.0004% (4 p.p.m.) by volume if the dilution factor was 500. For a 200-ft. stack, Church tentatively sets average dilution factors of 2,000 at 450 ft. (2.25 stack heights), 4,000 at 900 ft. (4.5 stack heights), and more than 10,000 at 1,700 ft. (8.5 stack heights). The average concentration at those points downwind from a 200-ft. stack may be estimated by dividing the stack concentration by those dilution factors.

Experience gained during World War II indicated that the ground-level concentration of a stack effluent was primarily related to windspeed changes and air-temperature-gradient changes (*4*). The work indicated that during the daytime the maximum instantaneous ground-level concentration was in the order of 0.2% to 0.5% of the stack concentration up to five stack heights downwind from a 200-ft. stack. At night, the stack effluent did not come to the ground until after it had traveled a distance equal to at least 10 and usually 20 to 30 stack-heights distance. Under typical nighttime conditions, the concentration of the stack effluent in the air near or at stack top level was inversely proportional to the square of the distance over the range tested, 15 to 35 stack-heights distance (*4*).

Wartime work also disclosed that there were two main types of flow patterns occurring regularly, one during daylight hours and the other during darkness hours. These flow patterns of stack effluents are dependent primarily on the vertical temperature gradient. These temperature gradients are also density gradients, and either assist or resist vertical motion in the atmosphere. When vertical motion is assisted, the atmosphere is said to be unstable. When

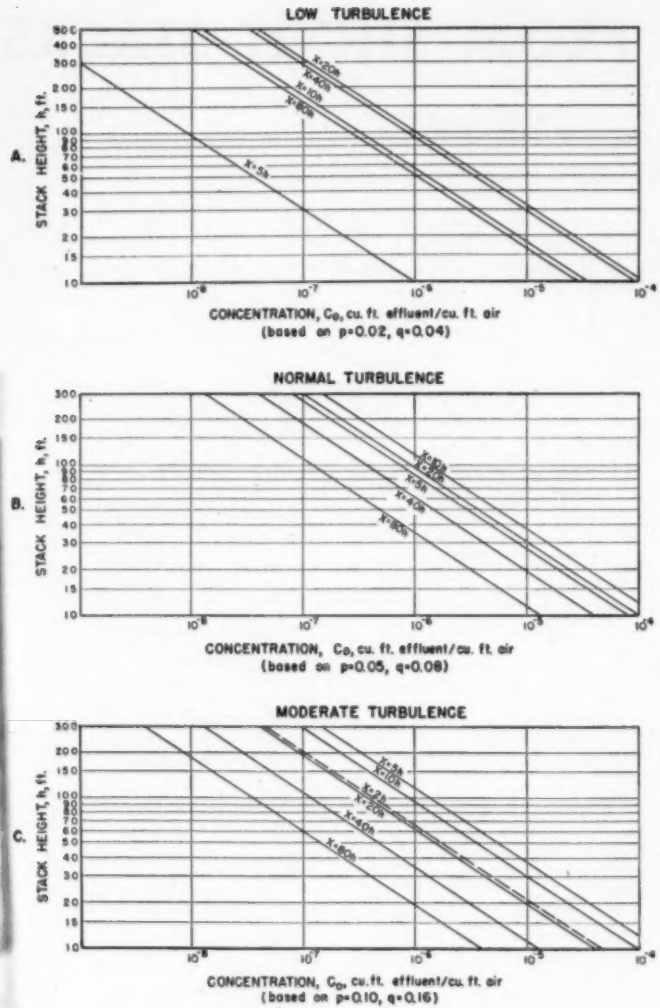

Fig. 1. Effect of stack height on time-average concentration.

vertical motion is neither resisted nor assisted, the atmosphere is said to be neutral. Figure 3 is a graph classifying these conditions at the test location. When the atmosphere is stable, the gases will remain in a thin layer at or near stack height and may flow for miles before coming to the ground, unless the flow is disturbed by mechanical eddies created by buildings or other surface features. When the atmosphere is unstable, the gases will become entrained in the vertical currents then always present, and may reach the ground at the stack base.

Study Procedures. After considering undertaking the study on a laboratory scale, a pilot-plant scale, and a plant scale, the latter was chosen.

The plant selected had an 80-ft. stack, which projected 20 ft. above a peaked roof that was 60 ft. to the crest. There were no other buildings more than 30 ft. high on the site, and those few were well scattered.

The site features were:

a. Flat, open terrain: sandy, grass-covered soil except marshy in one direction.
b. Single stack effluent: nitrogen oxides.
c. Stack effluent was unique to vicinity: only chemical plant for several miles.
d. Structure available for mounting weather instruments: water tower.
e. Emission rate of stack effluent known: continuously recorded nitrogen oxide-nitrogen dioxide concentration in exit gases.
f. Stack effluent gas subject to direct quantitative physical measurement: ultraviolet absorption.

Measurements. The several factors to be measured included: wind speed and direction at stack top and surface; air temperature gradients; ground-level concentration of the stack effluent; and ambient air temperatures. All these required continuous recording so that the data could be correlated in respect to time. Of the required instruments, the wind speed and direction recorder and the hygrothermograph were purchased; the mobile nitrogen dioxide gas analyzer and the temperature gradient recorder were developed by the Applied Physics Section of the Engineering Research Laboratory; the stack nitrogen dioxide gas analyzer was part of the plant's operating instrumentation.

a. **Vertical Temperature Gradient.** In order to measure the thermal stability of the air, it was necessary to have an instrument capable of continuously measuring and recording the different atmospheric temperatures between 10 ft. and 47 ft. and between 10 ft. and 84 ft. (these being convenient heights) within an error of ±0.05° C. To accomplish this, standard 100-ohm nickel resistance thermohms were selected as measuring elements. A specially modified electronic recorder was selected to record the measured temperature differences. The primary measuring circuit was a resistance bridge, one arm of which was connected to either of two resistance thermohms. An adjacent arm consisted of a third resistance thermohm. Balance was maintained by an automatic two-point recorder that switched the selected thermohm and recorded the corresponding temperature difference.

The thermohms were protected against radiation effects by a conical, polished, stainless steel shield. They were sealed to prevent water damage and wrapped with highly polished aluminum foil to reduce further radiation effects. During calibration, tests of this system showed that radiation equivalent to direct strong sunlight resulted in an average error of only ±0.03° C.

b. **Mobile Gas Analyzer.** In order to obtain gas concentration measurements a mobile, direct-reading photoelectric gas analyzer (*7*) was built.

Standardization of the instrument was accomplished by drawing air through an activated-carbon gas filter in series and ahead of the sample cell. The gas filter cell was sealed with porous stainless filters (rated at 5μ) and wool-felt filter cloth to prevent entrainment of carbon dust and its subsequent fouling of the sample cell. The instrument was brought to zero as frequently as was necessary by use of an external adjustment. If the sample cell had been dust-fouled or the analyzer had drifted, the zeroing operation cancelled those effects. The calibration chart for the analyzer is shown in Figure 4. Owing to instability and dead-zone of the analyzer, the error was as much as 0.75 p.p.m. This was not so small as desired but was considered satisfactory in light of the standard deviations of 2 to 6 p.p.m. for individual samples from the average, and that the best calibration checks were obtained at the

lowest concentrations. The counter dial was steady within one or two counts when no nitrogen dioxide was in the air.

c. **Sample Classification.** After mapping the plant and adjacent territory, it was planned to take samples at radial distances of 5, 10 and 20 stack heights; that is, at 400 ft., 800 ft. and 1,600 ft., respectively. Thus, there resulted three distance classifications. Twelve locations were picked at 400 ft., seven were picked at 800 ft., and three were picked at 1,600 ft. Because the primary interest was in distances close to the stack, it was planned to sample first at the 400-ft. and the 800-ft. locations.

On the basis of previous experience it was decided to divide atmospheric temperature-gradient conditions into three groups: unstable, neutral, and stable. For this installation, the atmosphere was considered unstable whenever the 84-ft. temperature was 0.31° C. or colder than the 10-ft. temperature. A neutral condition was defined as the case when the 84-ft. temperature was 0.01 to 0.30° C. colder than the 10 ft.-temperature. When the 84-ft. temperature was equal to or warmer than the 10-ft. temperature, a stable condition was said to exist (see Fig. 3).

Wind speed and direction were measured continuously at an elevation of 80 ft. The wind speed was considered to comprise three groups: 0–6, 7–13, and 14–20 mi./hr. Wind direction was not considered as a separate factor, since the samples were to be collected at predetermined points downwind from the stack.

d. **Sampling Procedure.** In procuring data on ground-level concentrations of the stack effluents, it had to be recognized that no control existed over the variables. Thus, it was necessary to repeat the samples at each location under selected similar conditions. Each test was run as follows: A sampling location was selected downwind from the stack. The jeep was driven to that location, the ultraviolet gas analyzer switched on, and a zero setting obtained. With the analyzer on, the indicator was watched. Whenever any nitrogen dioxide came by the jeep it was drawn into the analyzer through a sampling tube outside the jeep. The time was noted; the indicated concentrations were read at 10-sec. intervals and recorded. Each of these 10-sec. readings was considered as an individual point as if a series of evacuated flasks had been opened and the collected gases chemically analyzed. At the end of each test, the sample-cell temperature was noted and recorded, as was the sample location.

During the test the surface wind speed was measured with a small vane anemometer. The velocity was recorded at the end of the test. Attending weather conditions and supplemental information were noted.

The passage of the nitrogen dioxide-bearing eddies was intermittent, relatively infrequent, and from ½ to 3 minutes' duration at a spot. Each such eddy that resulted in at least one reading was considered as a test. After a number of tests had been accumulated, wind data, temperature-gradient data, stack gas concentration, and gas volume were obtained for the time of each test from the records previously described, and the data recorded. Later, each test was classified according to one of the 27 classes previously defined and placed aside for analysis. For example, these classes are written—Unstable, 0–6 V; this means the temperature gradient was unstable, the wind speed was 0–6 miles/hr., and the samples were taken at five stack-heights (400 ft.) distance.

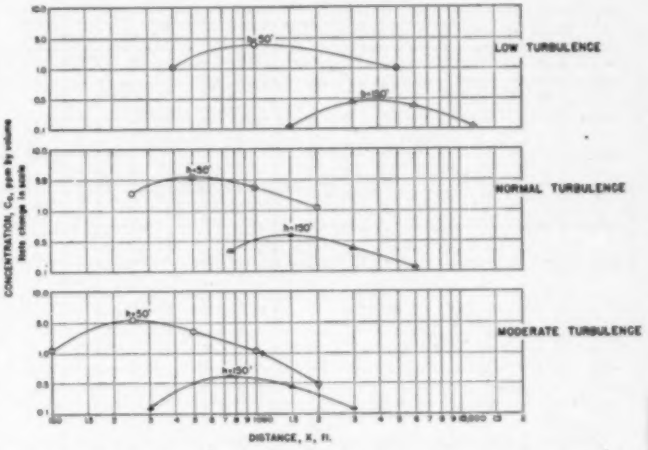

Fig. 2. Effect of turbulence, stack height, and distance on time-average concentration.

Test Data Procured. No data were taken at distances of 1,600 ft., nor during wind speeds of 14-20 miles/hr. Only six tests were made during the stable periods. Nearly all the data were confined to unstable lapse rates and neutral lapse rates, winds 0 to 13 miles/hr., and distances of five and 10 stack heights. It should be noted that these distances are close to the stack; hence the opportunity to test the formulas at large distances was not available.

Analysis of the Data. Data were analyzed to determine:

1. How the results of the tests compared with results predicted by the Bosanquet, Sutton, and Church formulas.
2. Range of concentration to be expected between averages and peaks.
3. Effects of wind speed, turbulence, and distance on the foregoing.

To do this the data were grouped according to the different classifications (unstable, 0–6, V, etc.). Concentration data were then adjusted to an emission rate of 10 cu.ft./min. at atmospheric temperatures and pressures and tabulated as shown in Table 1. Then, using the "F" test procedure (6), each group was compared to each other group that had only one variable different.

CONDITION	RANGE OF TEMPERATURE LAPSE RATE, °F./ft.
STABLE	+∞ to 0
NEUTRAL	0 to -0.0074
UNSTABLE	-0.0074 to -∞

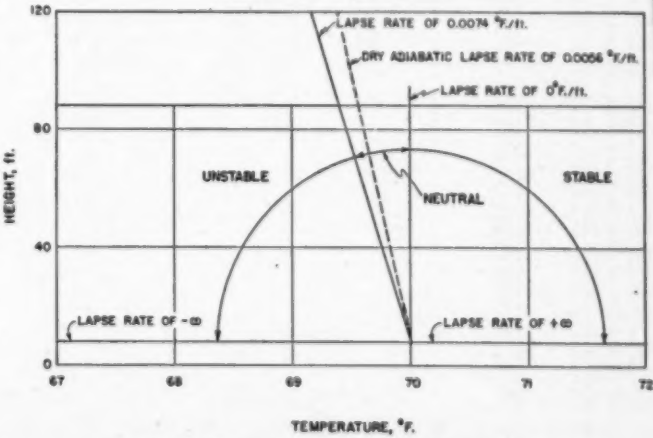

Fig. 3. Classification graph of atmospheric stability conditions.

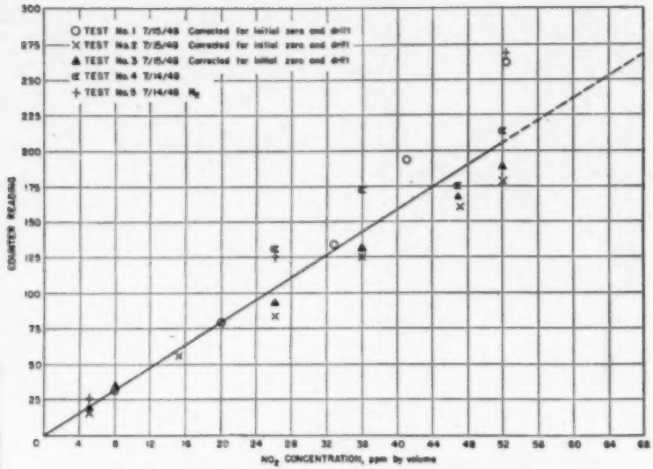
TEST No. 1 7/15/48 Corrected for initial zero and drift
TEST No. 2 7/15/48 Corrected for initial zero and drift
TEST No. 3 7/15/48 Corrected for initial zero and drift
TEST No. 4 7/14/48
TEST No. 5 7/14/48
COUNTER READING
NO2 CONCENTRATION, ppm by volume

Fig. 4. Calibration of ultraviolet analyzer No. 5 for NO_2 in air.

Groups not significantly different were not compared in the analysis. All tabulations and charts were then compared on a 10 cu.ft./min. basis (unless otherwise noted as in the following): For example, Unstable, 7–13, V was compared to Neutral, 7–13, V to see if the observed difference was statistically significant in light of the known variables.

Comparison of Results with Published Formula

For those groups that were significantly different, the following results were obtained. An important point to remember is that the values of the coefficients were preselected according to published values. Selection of different values for the coefficients will alter the expected concentration; for example, if $p = 0.10$ and $q = 0.16$ were selected for Bosanquet, the expected average concentration would be approximately doubled and the apparent agreement much better. This teaches that measurement or accurate estimation of the diffusion coefficients is necessary (*See* Table B).

Examination of the individual data shows that there is little choice among the methods to be used. As can be seen from Table B, the weighted time-average expected from the Sutton equation closely checks the actual time-average concentration. It does appear that the Sutton equation may produce large errors for points close to the stack, and did actually produce a result 100-fold too low for the condition; neutral, 7–13, and V.

Expected averages were calculated from $p = 0.05$, $q = 0.08$ for the Bosanquet equation; $n = 0.20$ (unstable), $n = 0.25$ (neutral) for the Sutton equation; and dilution factors of 2,000 at 400 ft. (five stack heights), and 4,000 at 800 ft. (10 stack heights) for the Church relationships. Since the latter are for a 200-ft. stack, and the actual stack height was only 80 ft., the agreement is suspiciously good. This led to a comparison of the ratio of the average

TABLE 1.—FREQUENCY OF MEASURED CONCENTRATIONS

X concentration from (by vol.)	$\sqrt{X}$ max.	Unstable, 0–6, V		Unstable, 0–6, X		Unstable, 7–13, V		Neutral, 7–13, V		Neutral, 7–13 X		Stable, 0–6, V	
		f	Σ%*	f	Σ%	f	Σ%	f	Σ%	f	Σ%	f	Σ%
0.1 to 0.5	0.71	2	3.9	3	5.7	34	17.7	7	11.1	7	4.6	1	3.4
0.6 to 1.0	1.00	12	27.4	8	20.8	27	31.8	8	25.4	17	15.8	2	10.3
1.1 to 1.5	1.22	7	41.2	6	32.1	26	45.3	5	33.3	6	19.7	2	17.2
1.6 to 2.0	1.41	8	56.9	4	39.6	23	57.3	8	46.0	24	35.5	6	37.9
2.1 to 2.5	1.58	2	60.8	7	52.8	17	66.1	5	54.0	13	44.1	6	58.6
2.6 to 3.0	1.73	4	68.6	1	54.7	19	76.0	6	63.5	11	51.3	2	65.1
3.1 to 3.5	1.87			7	67.9	12	92.2	2	66.7	9	57.2	2	72.4
3.6 to 4.0	2.00	4	76.5			5	84.9	6	76.2	10	63.8	1	75.9
4.1 to 4.5	2.12	2	80.4			12	91.1	2	79.4	5	67.1	2	83.8
4.6 to 5.0	2.24			1	69.8	3	92.7			8	72.4	1	86.2
5.1 to 5.5	2.34	1	82.3	1	71.7	2	93.8	2	82.5	5	75.6	1	89.6
5.6 to 6.0	2.45	4	90.2	1	73.6	4	95.8	1	84.1	3	77.6	2	96.5
6.1 to 6.5	2.55			1	75.5	1	96.4			7	83.2		
6.6 to 7.0	2.65	1	92.2			3	97.3	1	85.7				
7.1 to 7.5	2.74			2	79.2			2	88.9	4	84.9		
7.6 to 8.0	2.83	1	94.1	1	81.1	1	97.9			1	85.5		
8.1 to 8.5	2.92	2	98.0			1	98.4			2	86.8		
8.6 to 9.0	3.00					1	98.95	1	90.5	3	88.8		
9.1 to 9.5	3.08			1	83.0			1	92.1	3	90.8		
9.6 to 10.0	3.16									1	91.4		
10.1 to 10.5	3.24					1	99.5	1	93.6	2	92.8		
10.6 to 11.0	3.32												
11.1 to 11.5	3.40												
11.6 to 12.0	3.47												
12.1 to 12.5	3.54							1	95.2	1	93.4		
12.6 to 13.0	3.60			3	88.7								
13.1 to 13.5	3.68									2	94.7		
13.6 to 14.0	3.74							2	98.4				
14.1 to 14.5	3.81									2	96.0		
14.6 to 15.0	3.88									1	96.7		
15.1 to 15.5	3.94												
15.6 to 16.0	4.00												
16.1 to 16.5	4.07									1	97.4		
16.6 to 17.0	4.13			1	90.6								
17.1 to 17.5	4.19									1	98.0		
17.6 to 18.0	4.25												
18.1 to 18.5	4.30			2	94.3								
18.6 to 19.0	4.36									1	98.7		
19.1 to 19.5	4.42									1	99.3		
21.6 to 22.0	4.69			1	96.2								
23.1 to 23.5	4.85			1	98.1								
Total		50		92		191		62		151		28	
Avg. Conc. in Eddies		2.7		4.9		2.2		3.3		4.2		2.7	

* Based on $\Sigma f + 1$

(f = number of cases)

TABLE A.—VALUES OF SUTTON'S DIFFUSION COEFFICIENTS C_y AND C_z, FOR $n = 0.25$

Ht. Above Ground, meters	Values of C_y and C_z	
	$C_y = 0.21$	$C_z = 0.12$
0	0.21	0.12
10	0.12	0.12
25	0.10	0.10
50	0.09	0.09
75	0.07	0.07
100		

VALUES OF SUTTON'S DIFFUSION COEFFICIENTS (ENGLISH UNITS)*

Ht. above Ground, ft.	Values of C_y and C_z: $n = 0.20$ (moderate turbulence)	$n = 0.25$ (avg. turbulence)
0	$C_y = 0.42$ $C_z = 0.24$	$C_y = 0.24$ $C_z = 0.14$
33	0.42 0.24	0.24 0.14
82	$C_y = C_z = 0.24$	$C_y = C_z = 0.14$
100	0.23	0.13
150	0.21	0.12
200	0.19	0.11
250	0.18	0.10
300	0.16	0.09
350	0.13	0.07

* Other substitutions in Formula (2) must then be in consistent English units.

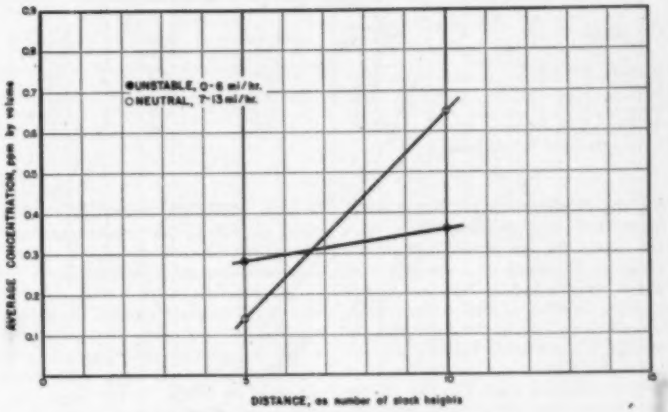

Fig. 5. Effect of distance on time-average concentration.

TABLE B.—EXPECTED vs. ACTUAL CONCENTRATIONS

Sample Condition	No. Tests	No. 10-sec. intervals	Wind[1] Speed ft./min.	NO_2 Emission Rate, cu.ft./min.	Conc. NO_2 in Stack, p.p.m. by vol.	Expected Time—Avg. Conc.,[2] p.p.m. by vol. Bosanquet	Sutton	Church	Actual Conc., p.p.m. by vol.
Unstable, 0–6, *Y*	9	148	478	16.6	3210	0.35	0.80	1.10	0.46
Unstable, 0–6, *X*	8	162	472	8.5	660	0.24	0.39	0.16	0.20
Unstable, 7–13, *Y*	23	1014	810	11.7	1530	0.14	0.33	0.76	0.41
Neutral, 7–13, *Y*	12	210	710	18.4	860	0.26	0.002[3]	0.43	0.35
Neutral, 7–13, *X*	19	1092	719	7.9	1100	0.22	0.19	0.28	0.51
Weighted Avg.						0.22	0.36	0.55	0.39

[1] All wind speeds refer to 80-ft. level.
[2] Calculated from actual stack conditions (not adjusted to 10 cu.ft./min.) for each test.
[3] Omitted from weighted average.

least dilution to the least dilution; this is discussed later.

Dilution Factors. When the stack concentrations were compared to the actual field concentrations, and the dilution factors (ratio: stack concentration/field concentration) calculated, the results were obtained as shown in Table C.

As given in Table C, the time-average dilution factor is the average at a point for periods of 30 min. or longer; the average least dilution is the average in the eddy, usually lasting 1 to 3 min.; and the least dilution is the minimum dilution that occurred, lasting only 1 to 10 sec. The reciprocal of the dilution factor multiplied by the stack concentration provides the field concentration to be expected. Dilution factors were not adjusted to 10 cu.ft./min. since the theory propounds that the volume rate of emission is not a factor in ground-level concentration.

The frequency distribution of the measured concentrations, adjusted to an emission rate of 10 cu.ft./min., is given in Table 1. The standard deviation and coefficient of dispersion about the average were calculated and are tabulated in Table D.

The standard deviations in Table D disclose that the probable variation in concentration is larger at 10 stack-heights than at five stack-heights distance. Dispersion coefficients show that there was little difference in the scatter about the average when unstable and neutral temperature gradients existed. When a stable gradient existed, the standard deviation shows that the probable variation in concentration is smaller and that the scatter about the average will be less than when neutral or unstable lapse conditions exist. It should be noted that the data do not agree entirely with (*4*), which states that the peak concentration is most likely at the stack base. These data show that there is little difference of importance between peak concentrations from the stack base up to 5- to 10-stack-heights distance.

Effect of Distance on Concentration. Equations (1) and (2) and Figures 1 and 2 will show that the average concentration at the ground should be low close to the stack, increase to a peak about 10 or 20 stack heights away (de-

TABLE C.

Condition	No. Tests	Dilution Factor: Time-Avg.	Avg. Least	Least
Unstable, 0–6, *Y*	9	4800	1017	183
Unstable, 0–6, *X*	8	3300	393	47
Unstable, 7–13, *Y*	23	3700	690	106
Neutral, 7–13, *Y*	12	3400	493	313
Neutral, 7–13, *X*	19	2160	373	60
Weighted Avg.		3360	568	130

TABLE D.

Sample Condition	Avg. Conc. in Eddy, *A*	Std. Deviation, σ	Coef. of Dispersion ($= \sigma/A$)
Unstable, 0–6, *Y*	2.7	2.2	0.8
Unstable, 0–6, *X*	4.9	5.7	1.2
Unstable, 7–13, *Y*	2.2	1.8	0.8
Neutral, 7–13, *Y*	3.3	3.4	1.0
Neutral, 7–13, *X*	4.2	3.9	0.9
Stable, 0–6, *Y*	2.7	1.5	0.55

TABLE E.

Sample Condition	Adjusted * Time-Avg. Conc., C_a	Avg. Conc.* in Eddy, C_e	Ratio C_e/C_a	No. 10-Second Intervals
Unstable, 0–6, V	0.28	2.7	9.6	148
Unstable, 0–6, X	0.36	4.9	13.6	162
Unstable, 7–13, V	0.35	2.2	6.3	1014
Neutral, 7–13, V	0.14	3.3	25.4	210
Neutral, 7–13, X	0.65	4.2	6.5	1092

* Adjusted to 10 cu.ft./min.

pending on the vertical diffusion coefficient) and then decrease. Data from this study do not extend beyond the distance of maximum concentration. When the comparable tests are plotted to show the effect of distance on average concentration, it can be seen that the average concentration was four times as great at 10 stack heights as at five stack heights distance (see Fig. 5) during neutral vertical temperature gradients (the basic condition of Bosanquet's formulas). For unstable conditions ($p = 0.10$, $q = 0.16$) Bosanquet's formula indicates that little difference should exist between five- and 10-stack-heights distance. This is the case as can be seen from Figure 5. Values plotted on Figure 5 were calculated from the actual concentrations adjusted to a constant emission rate of 10 cu.ft./min. (viz. $0.46 \times 10.0/16.6 = 0.25$ p.p.m.).

Since it is important to know the average maximum concentration at a point as well as the time-average concentration, the ratio of the two concentrations is compared in Table E.

The fourfold range in the ratios is considered large. However, the groups farthest out of line are those with relatively few samples, so it may be that complete data would show a narrower range in the ratios. If the single high value of 25.4 is ignored, it then appears that the average concentration when gas is present will be about 10 times the time-average concentration.

Frequency of Exposure of Single Points. One important point concerns the duration of the eddies at a point. Since they seldom lasted more than three minutes, the over-all time frequency was found to be low. In these tests it was found that in only 14% to 34% of the time was there a measurable conc.; the average was about 25%. This fraction, times the wind direction frequency, will give the over-all fractional exposure of a point to the stack gases. For example, if the wind is from the south 10% of the time, points 5 to 10 stack heights north of the stack will be exposed to the stack gases 2.5% of the time ($0.25 \times 0.10 \times 100 = 2.5\%$).

Probable Maximum Concentrations

Effects of Distance, Wind Speed, and Turbulence. Because interest in the dispersion of stack effluents concerns peak concentrations, as well as averages, the distribution of the individual point concentrations was analyzed to determine the chances for the occurrence of stated peak concentrations for selected conditions. To do this, the per cent cumulative frequency of concentration raised to the one-half power was plotted on arithmetic probability graph paper in accordance with the significance tests.

Five of the six cases previously listed have been compared to determine the variation in the peak concentration (97.7% cumulative frequency) with the different weather and distance classifications. The Stable, 0–6, *V* case has been omitted because theoretically no gas

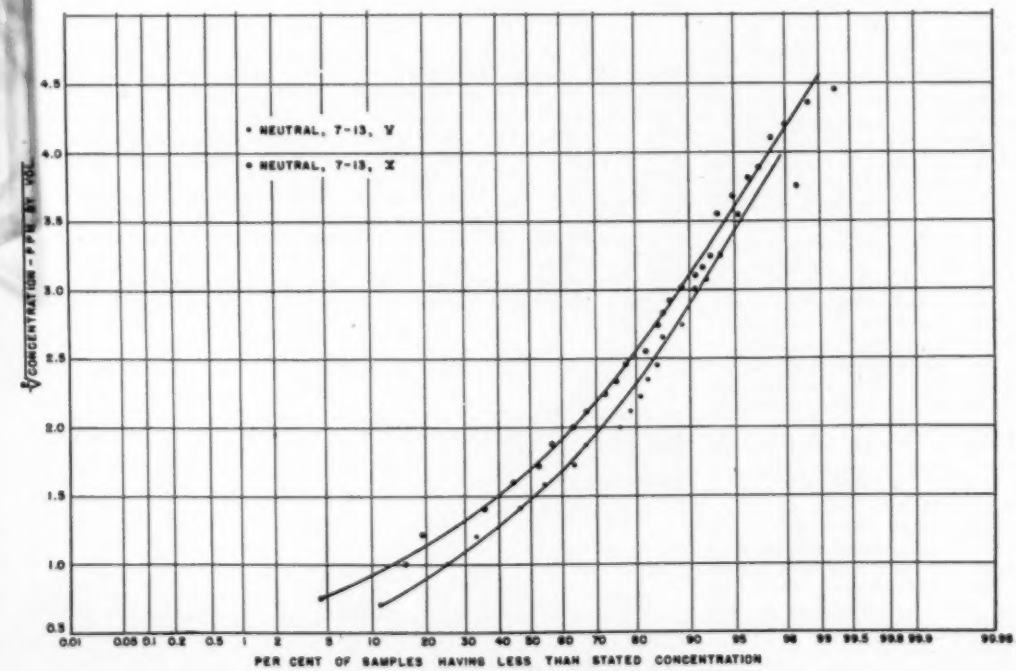

Fig. 6. Concentration probability during average turbulence.

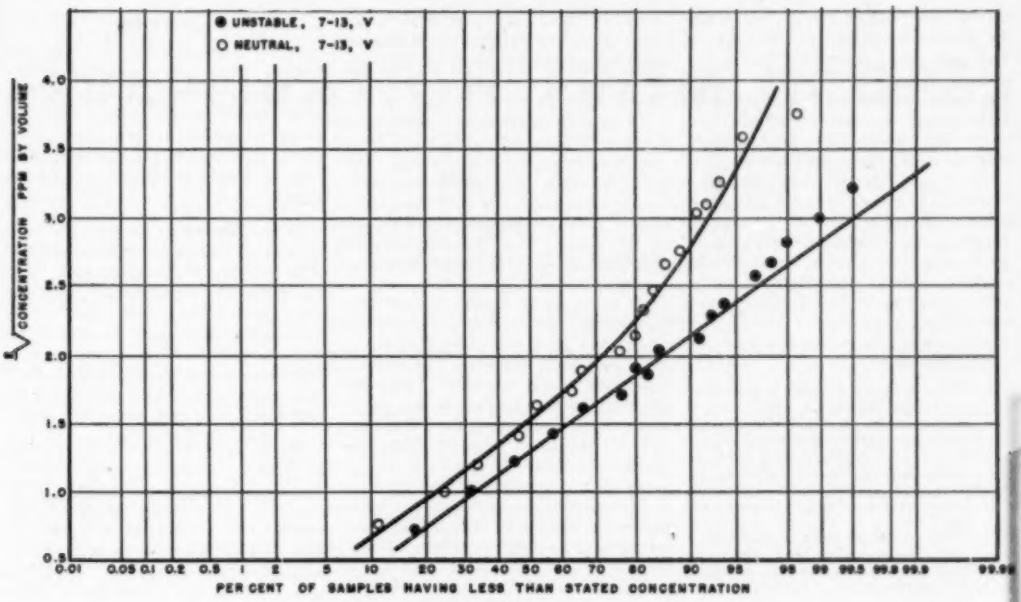

Fig. 7. Concentration probability during moderate winds.

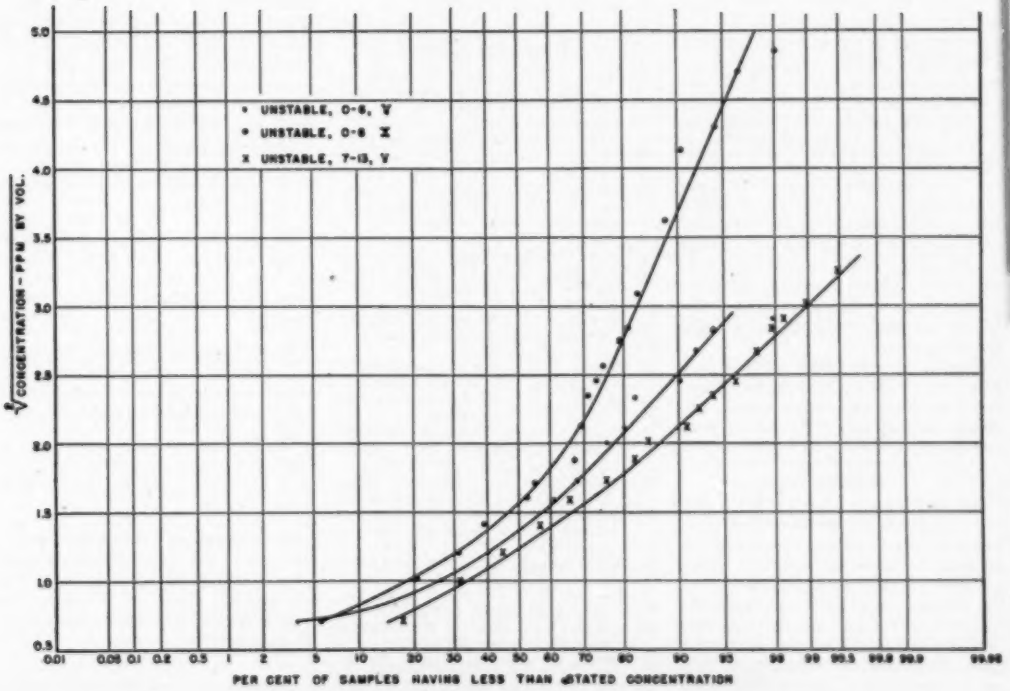
• UNSTABLE, 0-6, V
• UNSTABLE, 0-6 X
x UNSTABLE, 7-13, V
√CONCENTRATION - PPM BY VOL.
PER CENT OF SAMPLES HAVING LESS THAN STATED CONCENTRATION

Fig. 8. Concentration probability during moderate turbulence.

should have reached the ground under the defined conditions, and because so few tests were obtained. That gases occasionally do come to the ground during stable conditions is an anomalous fact, but was observed in this study. The writer also observed the same phenomenon on several occasions while working with Church at Hanford Engineer Works (*4*). On one occasion a barrage balloon tethered at 100 ft. or so suddenly dipped earthward and struck the ground. Such anomalies may be attributed to mechanical eddies created in the lowest 100 ft., or so, by buildings or other surface roughness features.

Considering the comparable cases, it can be seen that:

1. There is little difference in peak concentrations between 5 and 10 stack heights during average turbulence and moderate wind speeds (see Fig. 6);
2. At five stack heights during moderate winds, larger peak concentrations can be expected during average turbulence than during moderate turbulence (see Fig. 7);
3. When winds are light and turbulence is moderate, higher peak concentrations can be expected at 10 stack heights than at five stack heights (see Fig. 8);
4. At five stack heights during moderate turbulence higher peak concentrations can be expected when winds are light than when they are moderate (see Fig. 8).

In order to test whether stack height affected the ratio between the average concentration in the eddy and the peak concentration in the eddy, the data obtained in this study and data obtained during the war (*4*) were compared.

Data (from Table D, Neutral 7-13, V case omitted) from the 80-ft. stack showed that the peak concentration averaged 6.5 times the average concentration in the eddy. Available data from the 200-ft. stack showed that the peak concentration average 8.3 times the average in the eddy. Both of these apply to distances less than 10 stack heights. At greater distances the ratio should diminish, but no data were available to make that comparison.

The fact that the ratios differ by only 25% or so indicates that the eddies existed in the same proportional size though they of course differed in absolute values.

Summary

By selecting the proper diffusion coefficients, either the Sutton or Bosanquet relations may be applied to the solution of problems involving design of stacks for waste disposal to the atmosphere. If the diffusion coefficients reported in the literature are used, the equation will predict average concentrations that agree within twofold of the actual. This can be improved by better selection of coefficients. Use of dilution factors reported by Church also gave good agreement but probably cannot be expected to apply universally for 80-ft. stacks, especially since they were developed for a 200-ft. stack.

The average maximum concentrations close to the stack will be six to 13 times the time-average at those points. The probable extreme concentration for a few seconds will be three or four times higher than the average concentration in the eddies. Thus, the instantaneous maximum may be 50 times the time-average at a point.

A single point at the ground and aligned with the stack gas trail experienced stack gases only about 25% of the time, even when that point was directly downwind from the stack. Thus, the over-all exposure probability for points at ground level is considerably less than 25% of the time. Lines of equal exposure time can be drawn by taking wind direction frequency into account.

In considering air pollution problems, one must consider the time-average concentration at a point, the average maximum at a point, and the maximum at a point. These represent time intervals of one half to one hour, or more; one to five minutes; and one to ten seconds, respectively. The character of the effluent and the type of problem anticipated will determine which of the concentrations will be most important.

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Discussion

H. F. Johnstone (Univ. of Illinois, Urbana, Ill.): How do you know that the samples were always taken at the center of the cloud? I believe the equation you showed was for a point source, and if they were not at the center, this may account for variations from the theory.

C. A. Gosline: We arranged ourselves visually in a line at predetermined points downwind from the stack. This centerline was judged visually and from the wind direction record. Once located, samples were taken until the wind direction changed. Sometimes samples were taken near the center, but at other times were undoubtedly nearer the edge of the gas trail.

H. F. Johnstone: In the records made by the Thomas autometer for sulfur dioxide, just as a rough rule of thumb, I think this fact may be of some interest. In a considerable number of records, I observed that the average concentration over a half-hour interval, is usually about one fourth of the peak concentration. Now that doesn't mean too much but it helps sometimes in interpreting data.

C. A. Gosline: The ratio of the peak concentration to the average concentration is definitely associated with the length of period in question. In other words, the ratio of the peak concentration for 5 seconds to the 30-minute average is different from the ratio of the 2- to 5-min. average to the 30-minute average concentration. Because of the way that Thomas autometer operates the ratios you mention are more nearly the latter than the former.

W. K. Eister (Clinton Labs., Oak Ridge Natl. Lab., Oak Ridge, Tenn.): At what distance downwind from the stack were the concentrations determined?

C. A. Gosline: Reference was made to five and 10 stack-heights distance; the actual distances were 400 and 800 ft. (the stack top was 80 ft. above grade).

W. K. Eister: Then, what was the dilution you experienced at this point as a function of the air speed? How did this vary?

C. A. Gosline: This is described in the body of the paper. The stack gases were diluted at least 50-fold. This varied with air speed and distance. The lowest number of dilutions occurred at 10 stack heights.

(*Presented at Forty-third Annual Meeting, Columbus, Ohio.*)

EVAPORATION FROM DROPS

PART II

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Experimental Results for Pure Liquid Drops

Water Drops. Table 1 and Figure 6 present significant experimental results for evaporation from water drops. The points for heat transfer extrapolate close to the theoretical minimum value. Experimental values obtained for N_{Nu} at $N_{Re} = 0$ were slightly greater than 2.0, and the small difference is attributed to free convection. Although the data for heat transfer involved an inherently inaccurate correction for sensible heat, this correction was small; and because values of thermal conductivity are more reliable than values of diffusivity, the heat-transfer points are believed to be more accurate than the mass-transfer points. Data for mass transfer show a steeper slope and a lower intercept, but the disagreement is always less than 10 per cent at a given N_{Re} and is usually much less than 5 per cent. Factors which may have contributed to errors in the data and anomalies in the heat- and mass-transfer analogy were: (1) inaccurate values of diffusivity; (2) $p_{s\ell}$ may not have been the saturation vapor pressure; (3) the partial pressure of water vapor in the air may not have been zero at low air rates where the air stream velocity and the velocity of free convection were of the same order of magnitude and water vapor from the room air diffused into the jet; (4) free convection may have been significant at low values of the air velocity.

Figure 7 shows results for water drops evaporating into room temperature air where drop temperatures were not taken but estimated to be the adiabatic saturation temperature of the air. Figure 7 includes the data of Froessling (9) for water drops with diameters in a range from 0.064 to 0.18 cm. Figure 7 suggests three conclusions: (1) there is no diameter effect not accounted for by N_{Re}; (2) the assumption of a drop temperature corresponding to the temperature of adiabatic saturation in the case of water vapor-air mixtures is justified; (3) experimental results of Froessling and this investigation are the same, and differences occur only in analysis and interpretation of data.

Figure 8 shows a linear plot of D_p^2 vs. τ for an example evaporation test in still air. Since $(dD_p^2/d\tau)$ is constant, N_{Nu} and $N_{Nu'}$ are constant for all D_p. Substitution of experimental values for Figure 8 into Equations (19) and (20) gives

$$N_{Nu} = 2.23$$

and

$$N_{Nu'} = 1.79$$

If it is assumed that $N_{Nu'} = 2.0$ at $N_{Re} = 0$, then the data for still air can be used to obtain $D_v = 0.204$ sq.cm./sec. at an average temperature of 290° K. and a pressure of 741 mm. Hg., a low value compared with other methods of determination.

Tables 2 and 3 and Figure 9 show results for water drops evaporating at constant diameter into air at 66° to 90° C. and for suspended water drops evaporating with changing diameter into air at 85° to 221° C. Values of N_{Nu} for drops evaporating in hot air were calculated making the following assumptions: (1) $t_{s\ell}$ was taken as the temperature at which the thermal conductivity in the transfer path should be taken; (2) the drop was considered to be spherical with all of its surface available for transfer; (3) in estimating thermal conductivity the transfer path was considered to contain only air; and (4) the main air stream was considered to be of uniform temperature and velocity distribution.

For suspended drops evaporating in air at 85° to 221° C., N_{Nu} was obtained by applying Equations (19) and (20) to an analysis of the motion picture record. Values of $N_{Nu'}$ are not reported for drop temperatures above 40° C. because a small error in t_ℓ causes such a large error in $p_{s\ell}$ that the results have no significance. Although N_{Nu} for t_ℓ of the order of 200° C. calculated as outlined, tended to fall below the curve obtained for room temperature air, the difference was of the order of magnitude of the error involved in obtaining the data, and the correlations of Figure 6 were not impaired.

Equations for the correlation in Figure 6 were obtained as follows:

$$N_{Nu} = 2.0 + 0.60\, N_{Pr}{}^{1/3} N_{Re}{}^{1/2} \quad (21)$$

$$N_{Nu'} = 2.0 + 0.60\, N_{Sc}{}^{1/3} N_{Re}{}^{1/2} \quad (22)$$

Benzene Drops. Table 4 and Figure 10 show results for the evaporation of supercooled benzene drops in room temperature dry air. The drops evaporated while suspended from a capillary and their temperatures were measured with a ½-mil manganin-constantan thermoelement. Since the drops assumed a tear-drop shape with

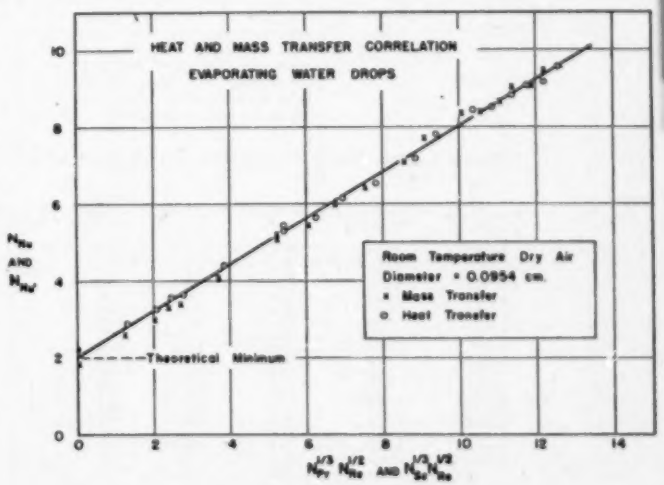

Fig. 6

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Part I of this paper (including Abstract) appeared in the March issue.

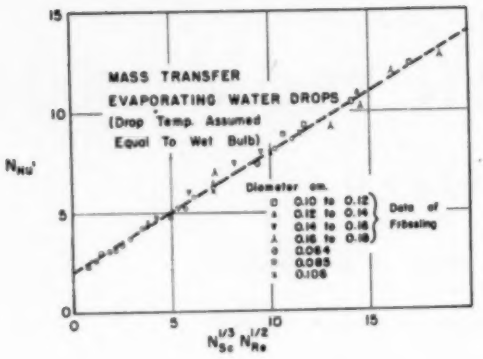

Fig. 7

the diameter along the axis of the capillary about 8 per cent greater than across the axis, D_p was taken as the arithmetic average of the two diameters. The diffusivity was calculated by the methods of Hirschfelder, Bird and Spotz (*12*).

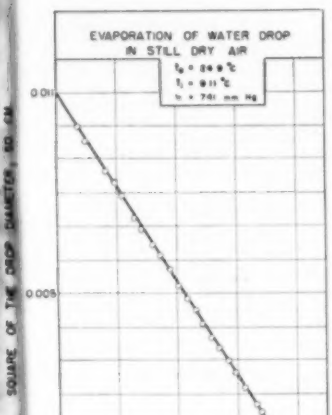

Fig. 8

The agreement with the mass-transfer correlation given by Equation (*22*) is excellent. Since $\Delta t/h_t$ for benzene represents about 20 per cent of the total heat flow to the drop, no attempt was made to obtain N_{Nu}. However, if approximately one half the apparent sensible heat flow was realized, the values of N_{Nu} for the evaporation of benzene were in agreement with Equation (*21*). This indicates that the average temperature of the feed liquid entering the drop was about that of the air stream one and one-half drop diameters above the drop.

Aniline Drops. Evaporation rate data for aniline drops suspended in a constant velocity air stream were taken to check the work of Froessling (*9*) and to determine the accuracy of his technique for substances of low volatility. For comparison, values of $(dD_p^2/d\tau)$ vs. $N_{Re}^{1/2}$ are shown in Figure 11 along with the results of Froessling's work. An uncertainty in this correlation was the value of the vapor pressure of aniline, which was quite small. Using the single value of Mack (*20*) in the low-temperature range and making corrections for comparison between data at 22° C. and 20° C., the experimental results expressed as $(dD_p^2/d\tau)$ appear to be in reasonable agreement with those of Froessling. However, with the indicated Δp_A, values of N_{Nu}' were nearly 10 per cent lower than the correlation obtained for water drops, and the slope of the line was 0.55 as Froessling suggested.

Discussion of Results on Evaporation from Pure Liquid Drops

Comparison with Other Data. In Figure 12 results of this investigation and the correlation of Equations (*21*) and (*22*) were compared with experimental data from the literature. Data of Froessling (*9*) and Maisel and Sherwood (*21*) were corrected to the value of D_v for water vapor used in this study. Data of Kramers (*17*) deviate from the correlation at low values of the Reynolds number because of free convection. Other data reviewed by Williams (*29*) can also be shown to agree with this correlation.

Figure 12 shows that the results of this investigation merged smoothly into the results of other investigations at higher Reynolds number, and that the empirical Equations (*21*) and (*22*) are remarkably accurate even when extrapolated five times beyond the experimental range in which they were determined. The over-all success of this correlation gives credence to the values of the exponents on N_{Pr}, N_{Re} and N_{Re}, as well as an implication that the calculated value of the diffusivity of water vapor in air may be more accurate than any reported in the literature.

Free Convection. Figure 13 presents evidence of free convection for the evaporation of water drops at constant diameter in still dry air. These experimental data for $N_{Re} = 0$ agree with Equation (*11*) shown by the dashed line. However, the experimental technique was not sensitive to free convection because the inherent errors involved were of the same order of magnitude as the effect and difficult to isolate. In contradiction, Figure 11 for the evaporation of a drop in still air with changing diameter indicated no free convection since the plotted points were on a straight line and t_L remained constant within 0.05° C. down to a droplet of minute size. To show the effectiveness of Equation (*11*), beyond

TABLE 1.—EXPERIMENTAL DATA FOR EVAPORATION OF WATER DROPS IN DRY AIR

Evap. Rate, ml./sec. × 10^5	Drop Diam., cm.	Air Vel., cm./sec.	Air Temp., ° C.	Drop Temp., ° C.	Atmos. Press., mm. Hg.	$\frac{kD_p}{k} = N_{Nu}$ Apparent	$\frac{kD_p}{k} = N_{Nu}$ Corrected	$\frac{k_g M_m D_{pp} f}{D_{vp}}$ N_{Nu}'	$\frac{D_p v_{\rho}}{\mu}$ N_{Re}
0.392	0.0954	246.	19.9	5.4	743	9.07	8.85	8.67	159.1
0.445	0.0954	210.	24.6	7.6	740	8.68	8.44	8.35	132.4
0.416	0.0954	172.3	24.9	7.7	740	8.05	7.80	7.70	108.4
0.388	0.0954	153.2	25.3	7.9	740	7.40	7.19	7.08	96.2
0.354	0.0954	119.7	25.4	8.0	740	6.74	6.54	6.41	75.1
0.320	0.0954	93.2	24.3	7.6	738	6.34	6.16	5.98	59.9
0.294	0.0954	76.2	24.4	7.6	738	5.83	5.66	5.47	47.9
0.277	0.0954	57.1	24.5	7.7	738	5.49	5.33	5.12	35.9
0.274	0.0954	57.1	24.5	7.7	738	5.44	5.29	5.07	35.9
0.227	0.0954	28.5	24.6	8.0	738	4.54	4.41	4.11	17.91
0.1890	0.0954	15.13	24.7	8.0	738	3.76	3.66	3.42	9.49
0.1839	0.0954	11.76	24.8	8.1	738	3.63	3.53	3.32	7.39
0.1674	0.0954	8.41	24.9	8.9	738	3.35	3.26	2.96	5.27
0.1479	0.0954	3.37	23.0	8.5	738	2.97	2.89	2.96	2.11
0.459	0.0954	286.	23.2	6.9	746	9.43	9.17	9.07	183.2
0.461	0.0954	267.	23.6	6.1	746	9.34	9.09	9.01	170.0
0.433	0.0954	228.	23.7	7.3	746	8.76	8.51	8.36	145.7
0.492	0.0954	306.	24.0	7.3	746	9.84	9.56	9.48	195.0
Still Air		0.	24.9	9.1	741	2.23	....	1.79	0

NOTE: Drop temperatures measured with 0.5-mil thermocouples.

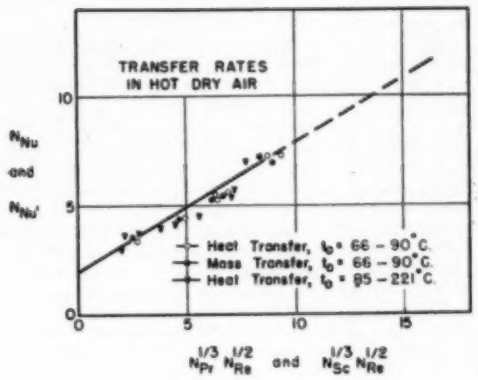

Fig. 9

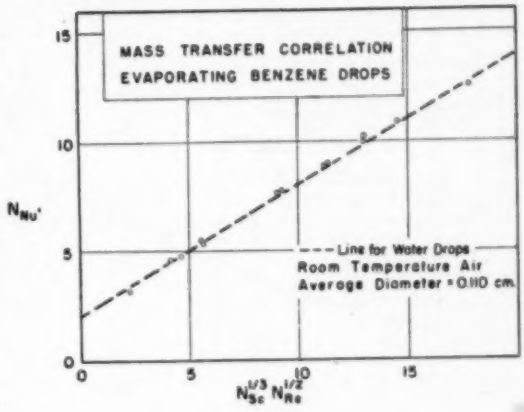

Fig. 10

the range of this investigation, experimental data of Meyer (*23*) and Elenbaas (*8*) were plotted in Figure 13.

Little consideration has been given to the experimental errors caused by free convection. In the work of Froessling (*9*) and in this investigation, free convection tended to oppose the main velocity; in the work of Kramers (*17*) it aided the main velocity; and in the work of Maisel and Sherwood (*21*) it partially aided in increasing transfer rates.

Drop Temperatures. To determine experimentally the temperatures of drops at various Reynolds numbers, the data of Table 5 were taken. In these tests a ½-mil thermocouple was inserted in the drop during evaporation, and the temperature was measured when drops where N_{Sc} was relatively much larger than N_{Pr}, the expected result of decreased $\Delta\rho_A/\Delta t$ and decreased t_i was realized since extraneous heat effects were not large enough to influence the general trend of the results.

At high air temperatures, measurement of the drop temperature was more difficult. The experimental drop temperatures in Table 3 for air temperatures above 85° C. were averaged over temperature ranges of about 5° C. Temperature lag was due to the fact that the drop started out at a temperature of roughly 10° C. and a high heat flux was required to bring it up to t_i. Experimental values of drop temperature for dry air at 220° C. appeared to be about 2° C. higher than the temperature of adiabatic saturation.

For practical purpose the temperature of adiabatic saturation is a good approximation to the temperature of evaporating water drops. For liquids other than water only wet-bulb temper-

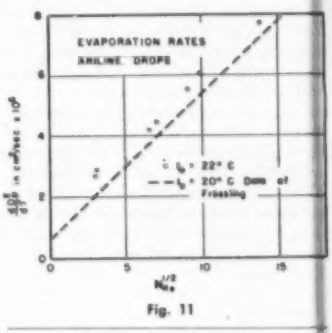

Fig. 11

TABLE 2.—DATA FOR EVAPORATION OF WATER DROPS AT AIR TEMPERATURES FROM 70 TO 90° C.

Evap. Rate, ml./sec. × 10^5	Drop Diam., cm.	Air Vel., cm./sec.	Air Temp., °C.	Drop Temp., °C.	Atmos. Press. mm. Hg.	$\frac{hD_p}{k} = N_{Nu}$ Apparent	$\frac{hD_p}{k} = N_{Nu}$ Corrected	$\frac{k_g M_m D_p p_f}{D_{op}}$ $N_{Nu'}$	$\frac{D_p v_{op}}{\mu}$ N_{Re}
1.47	0.085	230	90	....	740	7.9	7.3	7.0	101
0.90	0.085	110	77.5	....	740	5.9	5.3	5.3	50
0.91	0.085	110	78.7	....	740	5.8	5.3	5.3	50
0.91	0.085	110	78.7	....	740	5.9	5.4	5.3	50
1.56	0.095	183	84.	27.8	746	8.1	7.3	7.2	93
1.16	0.095	114	82.5	27.6	744	6.2	5.6	5.4	58
1.17	0.095	114	83.	27.8	744	6.2	5.6	5.4	58
0.73	0.095	55	66.4	24.1	744	4.9	4.5	4.3	29
0.62	0.095	17.6	71.4	24.8	744	3.7	3.4	3.5	9

NOTE: Where the drop temperature was not determined experimentally, the temperature of adiabatic saturation was assumed.

the drop had evaporated to the desired diameter and when no liquid was being fed through the capillary.

For no extraneous heat effects, the ratio of Equations (21) and (22) indicates that $\Delta\rho_A/\Delta t$ should increase with increased N_{Sc} where $N_{Pr} > N_{Sc}$. For water drops where N_{Pr} is slightly larger than N_{Sc}, the opposite seemed to be true although the trend was slight. For most practical purposes the temperature of a water drop can be taken constant for all Reynolds numbers. For benzene

TABLE 3.—EVAPORATION OF WATER DROPS IN DRY AIR AT ELEVATED TEMPERATURES. DATA FROM MOTION PICTURE RECORD.

$-\frac{d(D_p^2)}{d\tau}$ sq.cm./sec.	D_p corresp. to $-\frac{d(D_p^2)}{d\tau}$, cm.	Air Vel., cm./sec.	Air Temp., °C.	Drop Temp., °C.	$\frac{hD_p}{k} = N_{Nu}$	$N_{Re}^{1/2} N_{Pr}^{1/3}$
2.63×10^{-4}	0.085	184.	115	35.6	7.0	7.7
2.07	0.071	184.	115	35.6	5.5	7.0
0.89	0.056	18.8	85	29.4	3.6	2.1
0.71	0.049	18.8	85	29.4	2.9	2.0
5.3	0.096	184.	231	52	5.7	7.2
4.2	0.058	184.	231	52	4.5	5.6
3.3	0.086	77.	193	49	4.3	4.6
3.3	0.060	77.	193	49	4.0	3.8
1.56	0.101	21.	125	88.3	2.7	2.8

P = 743 mm. Hg.

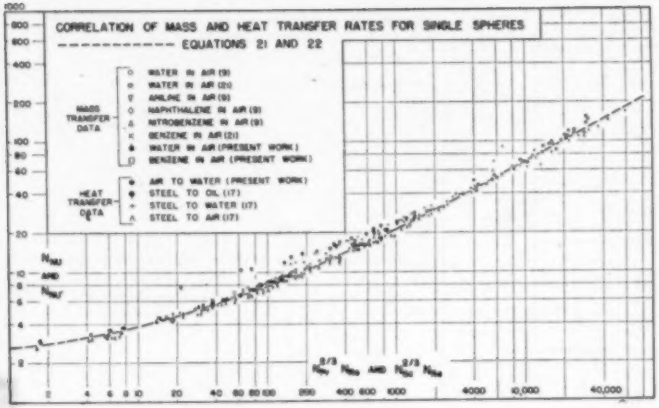
CORRELATION OF MASS AND HEAT TRANSFER RATES FOR SINGLE SPHERES
EQUATIONS 21 AND 22
MASS TRANSFER DATA
WATER IN AIR (9)
WATER IN AIR (20)
ANILINE IN AIR (9)
NAPHTHALENE IN AIR (9)
NITROBENZENE IN AIR (9)
BENZENE IN AIR (21)
WATER IN AIR (PRESENT WORK)
BENZENE IN AIR (PRESENT WORK)
HEAT TRANSFER DATA
AIR TO WATER (PRESENT WORK)
STEEL TO OIL (17)
STEEL TO WATER (17)
STEEL TO AIR (17)

Fig. 12

atures should be used to estimate the temperatures of the drop.

Extrapolation of Results to Higher Air Temperatures. At air temperatures of the range 300 to 500° C., Equations (*21*) and (*22*) must be used with care. From a practical standpoint Equation (*21*) for heat transfer is the preferred relationship for estimating evaporation rates at all temperatures since the thermal conductivity is better known than the vapor diffusivity. Its use, however, requires a value of drop temperature. This temperature can usually be taken as the wet-bulb temperature, and in the case of water the adiabatic saturation temperature. If radiation is contributing to heat flux, its effect must be estimated to obtain accurate evaporation rates.

The principal problem associated with high temperature is the proper averaging of the transport properties over a short transfer path. These properties may vary two- to fivefold in the boundary film. It is necessary, then, that a study of transfer phenomena at higher temperatures in dynamical systems be preceded by a more accurate determination of the values of transport properties and by a study of the effect of large gradients. In addition, other phenomena, such as thermal diffusion and transport of sensible heat by the diffusing component, should be considered under these conditions.

Evaporation from Drops Containing Solids in Solution and Suspension

Water Drops Containing Soluble Salts. A study was made of the assumption that water drops containing substances which lower the normal vapor pressure evaporate as though the drop surface was saturated regardless of the average concentration of the drop. Drawn up into the microburet were 50×10^{-5} ml. of aqueous solutions of various concentrations of NH_4NO_3 and they were fed out as a drop 0.106 cm. in diam., and the rate at which water had to be added to keep the drop at constant diameter was measured.

To estimate the temperature of the evaporating drop according to the above simplifying assumption, the adiabatic saturation line for the air conditions was drawn on a standard psychrometric chart. The intersection of this line with the line of partial pressure of water vapor over saturated aqueous solutions of NH_4NO_3, located p_{Ai} and t_i for the surface of the drop. Such a graphical solution for t_i is shown in Figure 14 where the partial pressure of water over saturated solutions of NH_4NO_3 is taken from Adams and Merz (*1*). For other liquids, the slope of the line must be determined from the ratio of the heat- and mass-transfer coefficients and not from an adiabatic saturation line.

Table 6 shows experimental and calculated values of evaporation rates where the calculated rate is the rate for pure water drops, based on Equation (*21*), corrected for sensible heat and for the reduced vapor pressure of a saturated solution. Even with the added internal turbulence due to feeding make-up solvent and the low evaporation rates with room temperature air, the evaporation rate for all concentrations was nearly that for the saturated aqueous solution of NH_4NO_3 at 12° C. Therefore, the assumption of saturation at the drop surface, regardless of the average drop concentration, appeared to be confirmed.

TABLE 4.—DATA FOR EVAPORATION OF BENZENE DROPS

Evap. Rate, gal./sec. $\times 10^5$	Drop Diam., cm.	Air Vel., cm./sec.	Air Temp., ° C.	Drop Temp., ° C.	Atmos. Press. mm. Hg.	$\frac{kD_p}{k} = Nu_v$ Apparent	$\frac{k_g M_m D_{pp'}}{D_{pp}} = Nu_v'$	$\frac{D_p v_\rho}{\mu} = Re_v$
1.51	0.110	5.1	24.4	3.5	733	3.3	3.2	3.7
2.10	0.110	15.3	26.4	3.4	732	4.3	4.5	11.1
2.54	0.110	28.9	27.1	3.1	736	4.9	5.5	21.
2.65	0.110	74.8	17.9	−1.8	739	6.3	7.8	57.
2.96	0.110	112.4	17.5	−2.5	739	7.1	9.0	86.
3.42	0.110	150.0	17.7	−2.3	739	8.1	10.3	115.
1.82	0.110	18.8	20.7	0.0	733	4.1	4.8	14.1
2.02	0.110	28.3	20.4	−0.4	733	4.5	5.4	21.
2.80	0.110	75.5	19.9	−1.0	733	6.3	7.7	56.
3.21	0.110	113.0	20.0	−1.1	733	7.1	8.9	84.
3.60	0.110	151.6	20.2	−1.1	733	7.9	10.0	113.
3.95	0.110	190.0	20.2	−1.0	733	8.7	10.9	142.
4.60	0.110	288.0	20.4	−0.94	733	10.1	12.6	220.

NOTE: Melting point of benzene = 42° F.

TABLE 5.—DROP TEMPERATURE AS A FUNCTION OF REYNOLDS NUMBER

Water		Benzene	
$t_0 = 21.7$° C.		$t_0 = 21.7$° C.	
$D_p = 0.0954$ cm.		$D_p = 0.110$ cm.	
Capillary diam. = 63μ		Capillary diam. = 74μ	
Drop temp., ° C.;	Reynolds No.	Drop temp., ° C.;	Reynolds No.
7.3	2.11	+1.1	2.5
7.3	9.55	−0.05	11.3
7.2	18.05	−0.1	21.3
7.1	48.0	−0.3	57.0
6.95	96.0	−0.85	114.0
7.0	120.2	−1.0	142.0
6.95	182.2	−1.05	215.0

(All drop temperatures were measured with a 0.5-mil manganin-constantan thermocelement.)

Similar tests with sodium chloride solutions did not give such clear-cut results since the saturation concentration of salt is low (about 26%) and has a much smaller effect on the vapor pressure of the solvent.

In applications with air temperatures of the order of 250° C., the ratio of Δt's for saturated solutions and pure water approach unity and the effect of solid in solution would become negligible in the constant-rate period.

Drying Drops in Still Dry Air with Heat of Crystallization and Supersaturation Effects. Although the drying time of a one millimeter drop in room temperature air may be greater by a factor of approximately 10^3 than the drying time in usual spray-drying operation, the history of such a drop is of interest in predicting phenomena which might occur in the latter case.

Figures 15*a* through 15*d* show D_p^2 and Δt vs. time for the evaporation of drops which contained dissolved and suspended materials, and were supported on a ½-mil manganin-constantan thermoelement in the special dryer described previously. So long as the drops presented a completely wetted surface to the drying air, $dD_p^2/d\tau$ and Δt are a measure of the drying rate at any time. During the falling-rate period, after a particle structure has been formed Δt may still be a measure of the rate of drying since it is a measure of heat transfer and consequently a measure of the rate of evaporation. Since the sequence of physical events is complicated by heats of solution and crystallization, changes in specific gravity, changes in density, and shrinkage of particle structure, the interpretations below must be considered to be primarily qualitative.

TABLE 6.—EVAPORATION RATES FOR DROPS CONTAINING NH_4NO_3

$N_{Sc} = 66.6$ $D_p = 0.106$ cm.

Avg. Conc. % NH_4NO_3	Air Temp. ° C.	Wet Bulb Temp. ° C.	Drop Temp. ° C.	Calc. Rate, ml./sec.	Exp. Rate, ml./sec.
26	28.2	9.4	12.0	0.360×10^{-6}	0.368×10^{-6}
46	29.4	9.5	12.0	0.364	0.367
50	28.5	9.5	12.0	0.366	0.365

Figure 15*a* shows results for the drying of a drop containing 3.0×10^{-4} g. of NH_4NO_3. The average concentration was controlled by drawing up a definite amount of standardized solution into the microburet and forcing it out onto a thermoelement ahead of excess solvent.

During the first period of drying up to the point of crystallization, $dD_p^2/d\tau$ and Δt remain effectively constant as predicted. The gradual fall in Δt during the first period of drying was probably real even though the conduction effect of the thermoelement wires was more apparent as the drop diameter decreased. This increase in drop temperature can be attributed to an increasing concentration in the surface (supersaturation evidently occurred since crystals appeared suddenly, covering the surface completely), and to the effect of heat of solution which is appreciable for NH_4NO_3 (as the salt concentrated, heat was evolved, t_i rose and Δt was no longer an exact measure of the evaporation rate). The rapid drop in Δt and rise in t_i at about 600 sec. was due to a high heat of crystallization evolved at this point (approximately 20 per cent of the latent heat of evaporation of water). As soon as crystallization of the supersaturated solution in the surface was complete, a lowering of t_i again occurred because moisture was still being evaporated.

Figure 15*b* presents data for the drying of a drop containing 1.9×10^{-4} g. of NaCl. Here supersaturation did not occur on the surface, but crystals appeared near the thermoelements as soon as those areas became sufficiently concentrated. Results show that the process exhibited a zone of decreasing Δt, and a zone of constant Δt, with $dD_p^2/d\tau$ constant throughout. As soon as a solid surface was formed the drop temperature increased and Δt fell rapidly. The zone of gradually decreasing Δt may be interpreted in the same manner as the first period of drying of the drop described in the previous paragraph (the original value of Δt can be estimated as in Figure 14); the zone of constant Δt may be interpreted as a condition of quasi-thermal equilibrium caused by crystallization (the value of Δt for this period can be estimated by drawing Equation (15) on Figure 14); the final zone, that of rapidly decreasing Δt, was the falling-rate period.

Figure 15*c* concerns the drying of an aqueous drop of nonsoluble, suspended green dye. Here Δt was nearly that expected for a pure water drop since the drop contained an inert material which did not affect the vapor pressure. Under these circumstances the drying was simplified, except for a shrinkage of the solid particle during the falling-rate period. The transition between constant-rate and falling-rate period was not sharp largely because of the fact that the surface became dried first in patches near the points where transfer was greatest (around the thermoelement wires at the top of the drop), and the

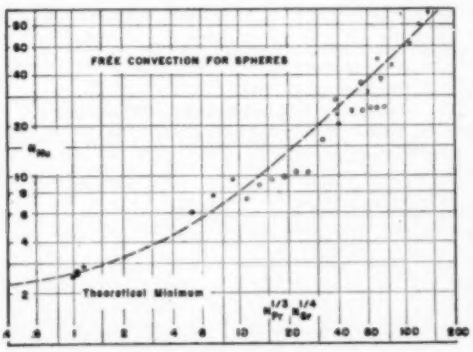

Fig. 13. Free convection for spheres

Air to evaporating water drop
Ice to water at 15° C. (23)
Ice to water at 30° C. (23)
Ice to water at 45° C. (23)
Silver sphere cooling in air (8)

Correlation Line:

$N_{Nu} = 2.0 + 0.60\ N_{Pr}^{1/3} N_{Gr}^{1/4}$

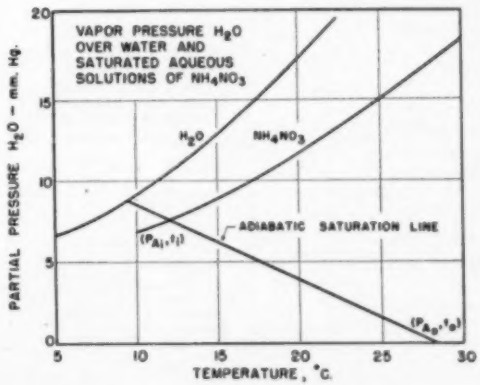

Fig. 14

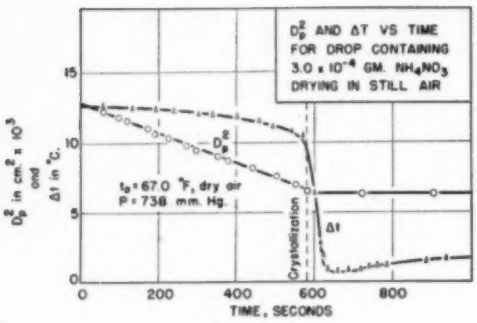
D_p^2 AND ΔT VS TIME
FOR DROP CONTAINING
3.0×10^{-4} GM. NH_4NO_3
DRYING IN STILL AIR
t_g = 67.0 °F, dry air
P = 738 mm. Hg.
D_p^2
Δt
Crystallization
D_p^2 in cm.^{2} x 10^3 and Δt in °C.
TIME, SECONDS

Fig. 15a

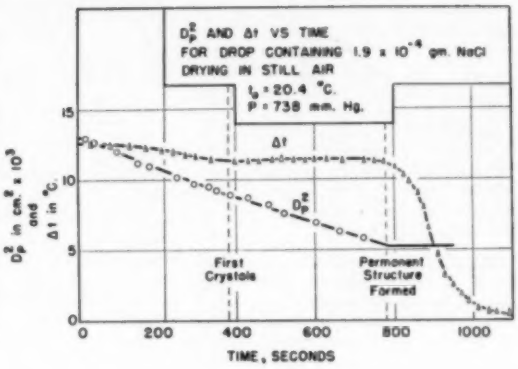
D_p^2 AND Δt VS TIME
FOR DROP CONTAINING 1.9×10^{-4} gm. NaCl
DRYING IN STILL AIR
t_g = 20.4 °C.
P = 738 mm. Hg.
Δt
D_p^2
First Crystals
Permanent Structure Formed
D_p^2 in cm.^{2} x 10^3 and Δt in °C.
TIME, SECONDS

Fig. 15b

whole surface was not in the same period of drying at the same time.

Figure 15*d* shows data for the drying of a drop of reconstituted dried whole milk. Results are similar to Figure 15*c*, including shrinkage during the falling-rate period. Again Δt is nearly that for pure water because milk exhibits only a slight lowering of the vapor pressure of water.

Because actual spray particles are atomized to about one-tenth diameters of the suspended drops used in these tests and because actual Δt's are on the order of ten times those used in these tests, the time of drying in spray drying will be of the order of 10^{-3} times the drying periods studied here. In so short a time the dynamic equilibrium for any one phase of drying may never be reached, and the physical picture represented by curves of the type shown in Figure 15 will be slurred and smoothed into a continually changing form not amenable to analysis. However, these results demonstrate some of the factors involved.

Formation of Solid Surfaces. In the theoretical treatment, saturation conditions in the surface of an evaporating droplet were predicted, but no criterion was developed for the conditions necessary for crystallization. This omission can be filled by assuming that crystals appear at any point on the surface where the rate of accumulation of nonvolatile material by evaporation exceeds the rate at which it diffuses into the center of the drop along concentration gradients. This assumption suggests the possibility that crystals can form before conditions for average saturation are reached and that crystals first form on the forward side of the drop where the rate of evaporation is greatest. The same statements should apply for drops containing suspended solids, but in this case the meaning of saturation and diffusion cannot be clearly defined.

To support the expectation that solid surfaces form before the average drop concentration reaches the saturation value, it was noted during the evaporation tests on the constant diameter drops reported in Table 6 that small crystals appeared at the bottom of the drop containing 46% NH_4NO_3 and that a crystal cap formed at the bottom of the drop containing 50% NH_4NO_3. Saturation concentration for aqueous NH_4NO_3 solutions at 12° C., the temperature of the drops, is approximately 61% which indicated a considerable concentration gradient existed from the surface of the drop into the interior.

This effect was even more striking in the case of a suspended drop of NH_4NO_3 solution evaporating in 210° C. air. The drop surface suddenly clouded with crystals after two seconds of evaporation when the diameter was 0.096 cm. and the average salt concentration was of the order of 0.5 g. of NH_4NO_3 to 1.0 g. of water. The surface temperature at that time must have been considerably higher than 51°C. which would be the surface temperature for a water drop under the same con-

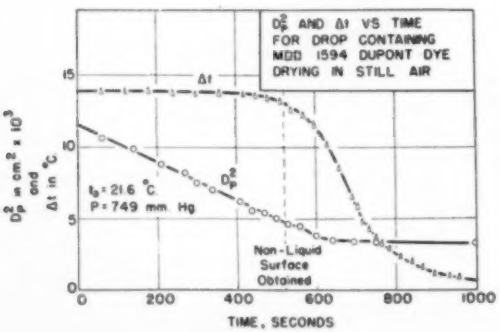
D_p^2 AND Δt VS TIME
FOR DROP CONTAINING
MDD 1594 DUPONT DYE
DRYING IN STILL AIR
Δt
t_g = 21.6 °C.
P = 749 mm. Hg.
D_p^2
Non-Liquid Surface Obtained
D_p^2 in cm.^{2} x 10^3 and Δt in °C.
TIME, SECONDS

Fig. 15c

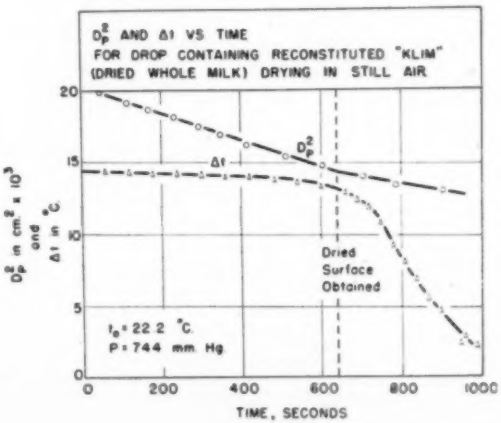
D_p^2 AND Δt VS TIME
FOR DROP CONTAINING RECONSTITUTED "KLIM"
(DRIED WHOLE MILK) DRYING IN STILL AIR
D_p^2
Δt
Dried Surface Obtained
t_g = 22.2 °C.
P = 744 mm. Hg.
D_p^2 in cm.^{2} x 10^3 and Δt in °C.
TIME, SECONDS

Fig. 15d

ditions. At 51° C. the concentration of NH_4NO_3 would have to be 3.5 g. of salt to 1.0 g. of water before crystals would appear. These crystals persisted for three more seconds up to a diameter of 0.090 cm. at which time the temperature of the surface had increased to about 170° C. and the crystals melted. At 100° C., the surface must have been supporting 8.7 g. of salt to 1.0 g. of water whereas the average concentration of the drop was considerably less than 3.0 g. of salt to 1 g. of water.

Qualitative Picture of Evaporation of a Drop Containing Sodium Chloride. Starting at a diameter of nearly one millimeter and a concentration of approximately 20 per cent a drop containing sodium chloride evaporated as a pure liquid drop until cloudy crystals appeared on the side of the drop facing the oncoming air stream. This crystal cap grew rapidly until it covered the whole drop with shiny white crystals. No appreciable change in diameter occurred after the crystal cap covered the surface. The crystal surface soon lost some of its luster, and blowholes into the drop appeared at the downstream side. These holes were attributed to a vacuum created by the removal of dilute solution from the center, which was relieved by a blowhole through the particle's surface. The picture was the same whether the drop was evaporated in a 200° C. hot air stream or in room temperature still dry air, the only difference in the two processes being the time of evaporation, 20 sec. vs. 2000 sec.

Estimation of Drying Time

For most cases of the drying of a single aqueous spray droplet, the evaporation rate for the first period of drying can be computed from an equation for the rate of heat transfer,

$$q_{ai} = hA(t_a - t_i) \qquad (23)$$

for which the required heat-transfer coefficient, h, for situations where radiation transfer is negligible, may be estimated from the relation

$$h = h_c = \frac{k}{D_p}(2.0 + 0.54N_{Re}{}^{1/2}) \qquad (24)$$

where Equation (24) is restricted to aqueous drops.

The drop temperature, t_i, can be estimated from a psychrometric chart at the point where the adiabatic saturation line drawn through the drying air conditions crosses the curve for humidity over a saturated solution of the nonvolatile material (Figure 14). If the nonvolatile material is in suspension without influencing the vapor pressure, the drop or surface temperature can be approximated by the temperature of adiabatic saturation in the case of water, or by the normal wet-bulb temperature in the case of liquids other than water. If crystallization is taking place, t_i may be estimated by a wet-bulb temperature given by Equation (15).

In applications to spray drying where atomization produces drop diameters of 100μ and essentially concurrent operation occurs, a further and conservative simplification can be made by using the limiting value of $h_a D_p/k = 2.0$ at $N_{Re} = 0$.

The first period of drying ends when the liquid surface of the drop becomes a solid surface. This may occur before conditions of uniform saturation throughout the drop are reached, and may result in a final particle of unusual porosity. Critical average moisture contents calculated from the data of Figure 15 are too meager to have meaning. Theoretical calculations of the time and average moisture content when internal liquid concentration gradients can no longer move the solute flux can be made but are so complex that they are of little practical use.

It can be shown from the heat balance on a drop with inert solids in suspension that during the falling-rate period the drying rate still may be estimated by Equation (23) if the proper average temperature difference can be determined. Thus, a heat balance for drying in still air gives the following expression for the falling rate:

$$\frac{dW}{d\tau} = \frac{6h}{\lambda D_{pc}\rho_s}(\Delta t) + \frac{C_s}{\lambda}\frac{d(\Delta t)}{d\tau} \qquad (25)$$

where now Δt is a variable, as shown in Figures 15*a* through 15*d*. Using the data of Figure 15*c*, it was calculated that down to a Δt of 1° C., the second term of the right side of Equation (25) accounts for only about 3% of the heat transferred. The same condition holds true for practical spray-drying operations. Thus, it might be concluded that for materials which do not crystallize from solution to give extraneous heat effects, the falling rate drying time for drops may be estimated by the expression

$$(\tau_2 - \tau_c) = \frac{\lambda D_{pc}\rho_s}{6h}\frac{(W_c - W_2)}{\Delta t_{avg}} \qquad (26)$$

where Δt_{avg} is a proper time average. In addition to the usual problem of specifying the proper critical moisture content, W_c, it is also necessary to know the value of D_p at W_c. Thus, an approximation for total drying time at low Reynolds number for drops containing undissolved solids may be written as

$$\text{Total drying time} = \frac{\lambda\rho_l[(D_{p1})^2 - (D_{pc})^2]}{8k(t_a - t_i)} + \frac{\lambda(W_c - W_2)\rho_s(D_{pc})^2}{12k\Delta t_{avg}} \qquad (27)$$

in terms of: original atomized diameter, D_{p1}; final particle diameter, D_{pc}; critical moisture content, W_c; final moisture content, W_2; final particle density, ρ_s; and the physical properties of the components of the system. Use of Equation (27) implies a knowledge of a relationship between moisture content and temperature. From the temperature data of Figures 15*c* and 15*d*, it appears that a logarithmic mean average temperature is a fair approximation of Δt_{avg} as far as the Δt curve goes since for the purpose of calculating drying time the curve may be characterized as an exponential decay curve. Such an assumption, which allows a slower rate of drying the lower the moisture content, is exactly equivalent to the usual assumption made in drying calculations that the rate of drying is proportional to moisture content when the drying air conditions remain constant. For spray drying in high temperature air with essentially concurrent operation, it is a well-known fact that the air temperature falls much more rapidly than the particle temperature increases. In Equation (27) this effect must be taken into consideration for an average $(t_a - t_i)$ during the constant-rate period and for a logarithmic mean average of the temperature difference during the falling rate period.

Acknowledgment

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Notation

A = area of transfer interface
C = heat evolved by crystallization per unit quantity of water evaporated from a saturated solution
C_l = specific heat of liquid drop
C_p = specific heat of gas at constant pressure
C_s = specific heat of particle per unit weight of solid
D_p = diameter of drop
D_{pc} = critical diameter of drop and dried particle

D_v = diffusivity of vapor in air
g = acceleration of gravity
h = rate of heat transfer per unit area of interface per unit temperature difference across the transfer path
h_c = rate of heat transfer by conduction and convection per unit area of interface per unit temperature difference across transfer path
k = thermal conductivity
$k_G = r_{Aoi}/\Delta p_A$ = rate of mass transfer per unit area of interface per unit partial pressure difference across the transfer path
M = molecular weight of liquid in the drop
M_m = average molecular weight of gas mixture in the transfer path
$N_{Gr} = D_p^3 \rho^2 g \beta \Delta t/\mu^2$ = Grashof number
$N_{Nu} = h_c D_p/k$ = Nusselt number
$N_{Nu}' = k_G M_m D_p p_f/D_v \rho$ = mass-transfer number analogous to Nusselt number for heat transfer
$N_{Pr} = C_p \mu/k$ = Prandtl number
$N_{Sc} = \mu/\rho D_v$ = Schmidt number
$N_{Re} = D_p \rho v_o/\mu$ = Reynolds number
$P = \pi/v_o^2 \rho$ = dimensionless pressure
p_A = partial pressure of diffusing vapor
p_{Ai} = partial pressure of diffusing vapor at interface
p_{Ao} = partial pressure of diffusing vapor in main gas stream
p_f = average value of $(\pi - p_A)$ across transfer path
$\phi_A = (p_{Ai} - p_A)/(p_{Ai} - p_{Ao})$ = dimensionless partial pressure
q_{oi} = rate of heat transfer per unit area of interface
$R = r/D_p$ = dimensionless radial distance
r = radial distance from center of drop
r_{Aoi} = rate of transfer of diffusing component per unit area of interface
t = temperature
t_i = temperature at interface
t_o = temperature in main stream
$T = (t - t_i)/(t_o - t_i)$ = dimensionless temperatures; also absolute temperature
T_r = absolute temperature of surroundings for calculating effect of radiation
v = velocity of fluid
v_r = velocity component perpendicular to interface
v_θ = velocity component parallel to interface
v_o = undisturbed velocity of main fluid stream
$\vec{v}$ = velocity of fluid as a vector quantity
$\vec{v}'$ = velocity of fluid in potential stream outside boundary layer (v_r' and v_θ' are radial and angular components of potential velocity)
$v_{f.c.}$ = velocity due to free convection $= (D_p g \beta \Delta t)^{1/2}$
$V_r = v_r/v_o$ = dimensionless radial velocity component
$V_\theta = v_\theta/v_o$ = dimensionless angular velocity component
W = moisture content, dry basis
K_1, K_2, m, n, p, q = arbitrary constants in correlation equations

GREEK LETTERS:

β = temperature coefficient of expansion $= 1/T$ for gases
δ = thickness of the boundary layer
Δ = difference in value of variable across the transfer path, e.g., $\Delta t = t_o - t_i$, $\Delta p_A = p_{Ai} - p_{Ao}$
π = total pressure; also mathematical symbol for 3.1416
σ = constant in the radiation equation
τ = time
ϵ = emissivity factor in radiation equation
θ = angular coordinate measured from the axis of flow
λ = latent heat of evaporation
ρ = density of the air
ρ_l = density of liquid in drop
ρ_s = weight of solid material per unit volume of particle

SUBSCRIPTS:

ai = per unit area of interface
A = for component A
c = critical moisture content
i = at the interface
o = in the main fluid stream
r = radial component
θ = angular component
1 = initial conditions
2 = final conditions

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CENTRIFUGAL DISK ATOMIZATION

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Centrifugal disks are widely used in spray dryers, humidifying equipment, and oil burners. This investigation reports a study of power consumption, drop size, drop-size distribution, and trajectory from a number of typical centrifugal disks operating over a wide range of conditions. General correlations were developed by means of which drop size and distribution from spray disks and power consumed by these disks can be predicted. Relationships proposed are in general agreement with data of other investigators.

ATOMIZATION of a liquid into a gas promotes intimate contact between the two phases. Heat, mass, and momentum transfer often can be accomplished in a matter of seconds or less. For this reason atomization has been the key to successful design and operation of such equipment as spray dryers, oil burners, humidifying equipment, and spray-gas contactors.

Three methods of atomization are commonly employed in the industry today. These are: pressure nozzles, two-fluid nozzles, and centrifugal disks. Many advantages and disadvantages of each type have been discussed in current literature (*10, 19, 21, 29*).

For numerous applications in spray drying centrifugal disk atomization is very attractive. These atomizers rarely plug. Erosion is seldom serious; and, even when it does occur, it seldom changes the operating characteristics of the atomizer. A gravity, or low-pressure feed can usually be employed. Changes in particle size from the atomizer caused by changes in feed-stock characteristics or production rates can usually be compensated for by a change in disk speed. Power costs, particularly in comparison with two-fluid atomizers, are generally low. Hence, this method of atomization, which is particularly suited to slurries, sludges, and high-viscosity, thixotropic materials, is employed in the majority of commercial spray dryers available to the process industries.

Despite the wide applicability of this method of atomization, there is virtually no reliable information which can be used by the process engineer for selection or design of the proper type and size of centrifugal disk. Nor is there any quantitative information which will tell him the effect that the various operating variables might have on the spray which is produced.

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Previous Work

Centrifugal disks have long been known to be effective atomizers, particularly for spray dryers. General descriptions of the more common types are easy to find (*2, 4, 8, 10, 18-21, 25, 28, 29, 31, 33, 35*). In general their operation depends upon feeding a liquid, or semiliquid, to a rotating element from which it is thrown in a radial direction by centrifugal force. The high velocity of the liquid leaving the rotor plus the fact that it is diverging promotes disintegration of the liquid into small drops. Specific rotor designs plus specific methods of feeding the liquid to the rotor and driving the rotor are the subjects of more than 60 United States patents issued in the 60 years following de Kinder's patent (*9*). It is therefore unusual to find that, despite the age and widespread use of the art of centrifugal atomization, there were, until recently, no quantitative data on this operation.

Drop-size and distribution data from centrifugal disks are meager, despite claims that various disk designs will give a spray of more uniform particle or finer particle size than others. Bär (*3*) reported two different mechanisms for atomization from centrifugal disks. In one mechanism, surface forces predominated and individual drops were purported to be disengaged from the periphery of the rotating disk. This might be expected at low feed rates to the disk. The theoretical equation which Bär derived for this case was:

$$D_{mss} = \frac{0.525}{n}\left(\frac{\sigma}{r\rho}\right)^{0.5} \qquad (1)$$

The diameter defined by this equation was the maximum diameter which a droplet could attain before disengaging from the disk. Small satellite drops were also formed. Bär found that this equation was satisfactory for materials having low viscosity but gave low values for viscous materials.

The second mechanism postulated was "velocity spraying." This mechanism implied that the liquid broke up after leaving the disk by its impact and friction with the surrounding atmosphere. This mechanism was predominating at high flow rates and when the fluid issued from rotating nozzles. For this case, Bär gave the equation:

$$D_{mss} = \frac{0.102\sigma}{n^2 r^2 \rho_a} \qquad (2)$$

However, the maximum drop sizes measured from atomizers supposedly operating to give velocity spraying were two to five times greater than those predicted from Equation (*2*), with materials of greatest viscosity giving the largest drop size.

Walton and Prewett (*33*) found that a relatively uniform drop size could be obtained from a rotating disk when the feed rate was kept low. This drop size could be represented by an equation similar to Equation (1) proposed by Bär; namely:

$$D_{mss} = \frac{0.428}{n}\left(\frac{\sigma}{r\rho}\right)^{0.5} \qquad (3)$$

They also found that the large drops were accompanied by a number of satellite drops considerably smaller than the diameter defined by Equation (*3*). These satellite drops increased in number with increasing feed rate. Their explanation of the formation of the uniformly sized large drops was essentially the same as that proposed by Bär for his first mechanism.

Muraszew (*23*) in a paper unsubstantiated by data presented the same formula, Equation (*3*), as Walton and Prewett for the drop size of fuel oil atomized from small centrifugal disks operating at high speeds. For more ordinary operation, presumably at lower speeds and greater flow rates, he suggested a modification of the Triebnigg (*30*) formula as follows:

$$D_{mss} = \frac{4\sigma}{\psi V^2 \rho_a} \qquad (4)$$

Except for ψ, the air resistance coefficient, the formula is similar to Equation (*2*) of Bär if $2\sqrt{2}\pi nr$ is substituted for V.

Hinze and Milborn (*15*) studied atomization from a rotating cup and found three different types of flow leaving the edge of the cup. These were: (a) direct drop formation, (b) ligament formation, and (c) film formation. Presumably the equations of Bär and Walton and Prewett would apply to the first type. Some data on drop size from the cups were given, but no expression for predicting the size was presented.

In addition to the quantitative data available in the preceding references, a number of qualitative statements concerning the effect of the operating variables on drop size can be found (*10, 18, 19, 28, 29, 32*). In general it is claimed that an increase in drop size can be obtained from: (a) a decrease in the rate of rotation, (b) an increase in feed rate, and (c) an increase in viscosity. The effect of liquid surface tension, liquid density, disk radius, and disk design on drop size is not known even qualitatively.

There are some claims in patents that drop-size distribution can be affected by disk design, but there are no substantiating data. The only complete data on the particle size from centrifugal disks that are available (*1, 15*) are too limited to draw any conclusions on the effect of the operating variables on the drop-size distribution.

Equations for estimating the net power required to drive centrifugal disks are available (*10, 19, 29*). The equations, which are identical, are based on accelerating the liquid to the speed of the disk and are of the form:

$$P_h = 1.03 \times 10^{-5} \Gamma r^2 n^2 \qquad (5)$$

This expression does not include friction or windage losses. For smooth cup- or saucer-shaped disks, the power is reported to be somewhat less because of slippage on the disks. Actual data on power consumption of centrifugal atomizers has been presented by Philip (*25*). However, he neglected to state the disk dimensions so it is impossible to compare his data directly with Equation (5), although the effect of the operating variables was similar to that which would be predicted.

Theory

Several theories have been postulated covering centrifugal disk atomization as well as atomization in general. All the investigators will more or less concede three possible mechanisms but are often in severe disagreement as to which one may predominate under any given set of conditions.

It is generally agreed that, at relatively low flow rates, atomization can occur by the action of gravity or centrifugal force overcoming the surface forces holding a liquid to a solid surface. This is illustrated by the drops obtainable from a medicine dropper. This also represents the case for centrifugal disks postulated and observed by Bär, Walton and Prewett, Muraszew, and Hinze and Milborn. Thus, Equations (1) and (3) can be derived from a simple balance of forces. The constant will differ somewhat depending upon the shape assumed for the drop immediately prior to its release from the solid surface. Bär derived his constant theoretically, while Walton and Prewett obtained it experimentally by measuring the drops formed by gravity from the bottom of horizontal flat plates. This method of atomization requires that the liquid wet the surface from which it is being atomized and that the kinetic energy of the liquid entering the drop before formation be negligible. All three investigators reported that satellite drops smaller than the predicted drop size were also formed. This might be attributable to the kinetic energy effects of the liquid traveling at high velocity into the drop before its ultimate formation or to air friction effects on the liquid either on the disk or as it leaves the disk.

This suggests the second theory for atomization; namely, that it is caused by the impact and friction of the liquid with the surrounding atmosphere. This method was suggested by Castleman (*5*) and is substantiated by considerable data on the break-up of liquid jets. Bär (*3*), Triebnigg (*30*), and Hinze (*14*) have all presented theoretical equations for the maximum size of a liquid drop which can withstand impact with an air stream of a given velocity. The derivation of all these equations is complex, and all are based on various assumptions of pressure patterns around the drop and the role of viscosity in preventing drop deformation. None of these equations has ever been completely validated with experimental data. They all are of the general form which states that N_{We} is a constant for drop break-up, i.e.,

$$(N_{We})_{crit.} = \frac{\rho_a V^2 D_{max}}{\sigma} \qquad (6)$$

For centrifugal disks,

$$V = 2\sqrt{2}\pi r n \qquad (7)$$

so that

$$(N_{We})_{crit.} = \frac{8\rho_a \pi^2 r^2 n^2 D_{max}}{\sigma} \qquad (8)$$

From theoretical considerations Bär estimated $(N_{We})_{crit.} = 8$ (cf. Equation (3)) and experimentally found it to be two to five times greater. From the experimental work of Merrington and Richardson (*22*), Hinze (*14*) estimated $(N_{We})_{crit.} = 20$ for single drops of nonviscous liquids falling through air. This is in fair agreement with Bär's experimental data.

The third possibility is that atomization may result from readjustment of shear stresses within a liquid after it leaves the confining surfaces which set up these stresses. Thus atomization might result from the interaction of internal velocity gradients and surface tension as suggested by Haenlein (*11*) without any influence from the surrounding air. This has been investigated by Rayleigh (*27*) and Weber (*34*). Pictures of jets introduced into vacuum (1 mm. Hg abs. pressure) by Lee and Spencer (*17*) show that break-up does occur which can be attributed to disruptive effects other than air drag. This may be expected particularly when the liquid is in turbulent flow.

Since all possible causes for atomization might be occurring simultaneously on centrifugal disks and since a rigorous theoretical analysis would of necessity be extremely complex and subject to numerous assumptions, it was decided in this investigation to consider the problem of atomization from the standpoint of dimensional analysis. Variables which were thought to be of consequence were:

1. Flow rate from disk expressed in mass flow per unit periphery for discharge, Γ
2. Disk radius, r
3. Disk speed, n
4. Total wetted periphery of the disk, L
5. Liquid viscosity, μ
6. Liquid density, ρ
7. Liquid surface tension, σ
8. Surface-per-unit-volume drop diameter, D_{sv}

These variables could be related by dimensional analysis in the following manner:

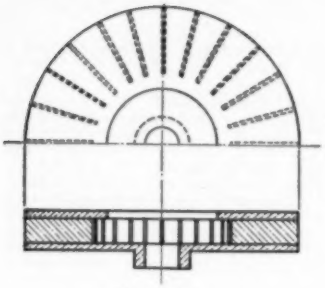
$$\frac{D_{sv}}{r} = K\left(\frac{\Gamma}{\mu}\right)^a \left(\frac{\Gamma}{\rho n r^2}\right)^b \left(\frac{\Gamma^2}{\sigma \rho L}\right)^c \left(\frac{L}{r}\right)^{a+b+3c+f} \qquad (9)$$

These groups are similar to those developed by Hinze and Milborn (*15*) but with a slightly different arrangement of the variables. Groups having the exponents a and b are concerned with the ratio of inertial to viscous forces of the liquid leaving the disk and are a Reynolds number. The remaining terms are obtained by considering the ratio of inertial energies to surface energies and are therefore a Weber criterion. Other groupings could be used, but since these had the disk speed in only a single term and since this was found to be the major cause of drop-size variation, these groupings were used for purposes of drop-size correlation.

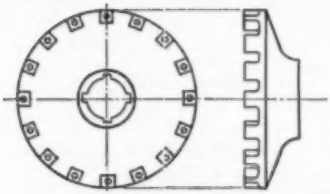
The break-up of liquids is too complex to permit the development of theoretical relationships expressing the drop-size distribution from centrifugal disks. It is sufficient to expect that the drop size at low flow rates from a disk might be uniform if Bär's proposed mechanism for drop formation is correct. At high flow rates, the drop-size distribution might be expected to be definable by a probability function.

Similarly, the complex interaction of the spray from the disk with the surrounding air, setting up air currents around the disk, make theoretical analysis of drop trajectory from a disk virtually impossible. If the drops are extremely large and air currents are negligible, the equations developed by Lapple and Shepherd (*16*) for the trajectory of single particles might be used to estimate the path of the spray. Such cases would probably be rarely encountered.

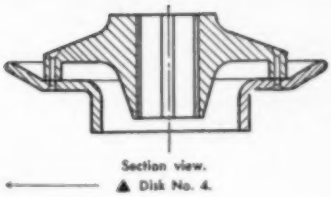
The theoretical Equation (5) for the net power required to drive a centrifugal disk is easily derivable if it is assumed that a frictionless liquid having



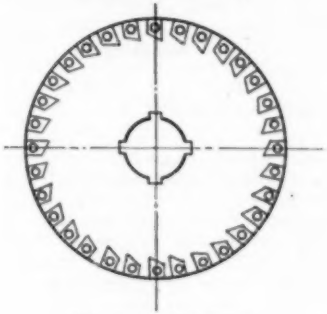
Section view.
▲ Disks Nos. 1, 2, and 3.



Plan view—without shroud.

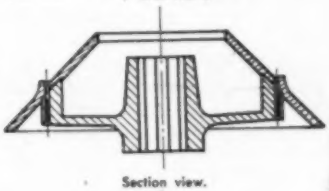


Section view.
◀ ▲ Disk No. 4.



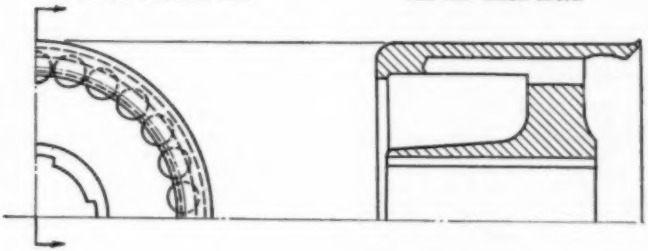
Plan view—without shroud.

◀ ▼ Disk No. 5

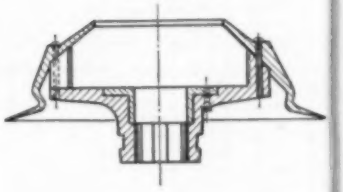


Section view.

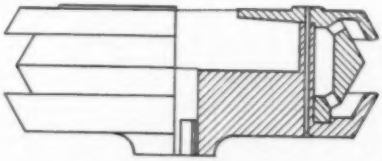
▼ Disk No. 6. Section view.

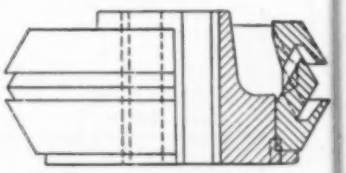


▼ Disk No. 7.
Section view.

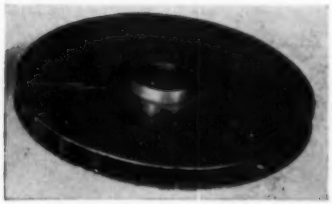


Disk No. 8
One-half section view. ▶

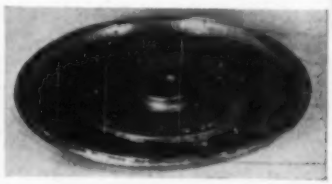




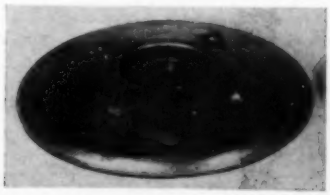
▲ Disk No. 9.
One-half section view.



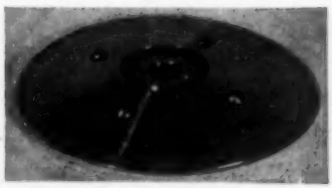
Disk No. 10.

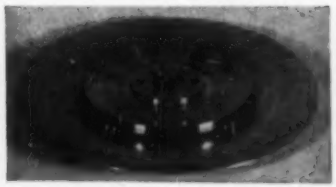


Disk No. 11.



Disk No. 12.





Disk No. 13.

Fig. 1. Disks used in centrifugal-disk-atomization study

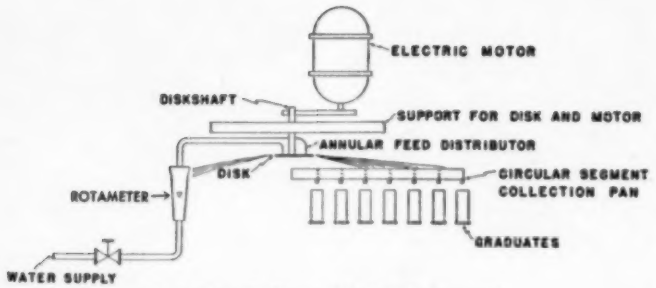


Fig. 2. Schematic diagram of equipment arrangement.

no slip on the disk is being atomized. This has been done by Marshall and Seltzer (*19*). Adler and Marshall (*1*) have modified this Equation (5) slightly to cover the case when the liquid is fed at a point other than the center of the disk. Theoretical equations taking into account friction of the liquid on the disk would be extremely complicated and would not significantly change Equation (5). Any change would result in less power than that predicted by Equation (5), thus making this equation conservative for design purposes.

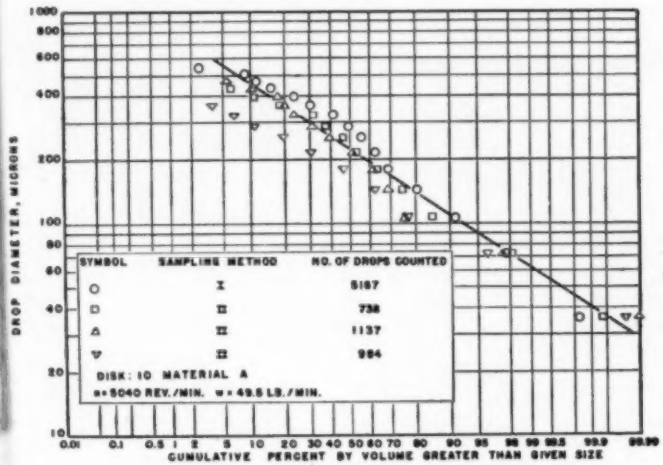


Fig. 3. Reproducibility of drop-size distribution measurements.

TABLE 1.—DISK SPECIFICATIONS

Disk No.	Description	Radius, r, ft.	Wetted Periphery per Stream L, ft.	Number of Streams from Disk, Z	Direction of Film Movement, θ (angle from horizontal) and β (angle from radial)
1.	Radially vaned	0.146	0.031	24	$\theta = 0°$, $\beta = 0°$
2.	Radially vaned	0.208	0.031	24	$\theta = 0°$, $\beta = 0°$
3.	Radially vaned	0.333	0.026	24	$\theta = 0°$, $\beta = 0°$
4.	Single-edge	0.167	1.048	1	$\theta = 30°$, $\beta =$ indeterminant
5.	Single-edge	0.208	1.310	1	$\theta = 45°$, $\beta =$ indeterminant
6.	Single-edge	0.104	0.654	1	Initially,* $\theta < 0°$, $\beta =$ indeterminant
					Finally, $\theta = 45°$, $\beta =$ indeterminant
7.	Single-edge	0.240	1.510	1	Initially, $\theta = 90°$, $\beta =$ indeterminant
					Finally, $\theta = 20°$, $\beta =$ indeterminant
8.	Double-edge	0.256	1.610	2	$\theta = 60°$, $\beta =$ indeterminant
9.	Double-edge	0.167	1.048	2	$\theta = 45°$, $\beta =$ indeterminant
10.	Type *V* No. 74-75 (forward curving vane at periphery)[1]	0.214	0.031	24	Initially,* $\theta = 0°$, $\beta = 104°$
					Finally, $\theta = 0°$, $\beta = 26°$
11.	Type *C* No. 10 (cup shaped)[1]	0.208	1.310	1	Initially, $\theta = 15\frac{1}{2}°$, $\beta =$ indeterminant
					Finally, $\theta = 90°$, $\beta =$ indeterminant
12.	Type *C*, 2-in. diameter (cup shaped)[1]	0.083	0.524	1	Similar to Bowen, Type C, No. 10
13.	Type *CRE* No. 4 (flat saucer)[1]	0.239	1.440	1	Initially, $\theta = 19°$, $\beta =$ indeterminant
					Finally, $\theta = 0°$, $\beta =$ indeterminant

[1] Bowen Engineering, Inc.
* *Initially* refers to point at which liquid is introduced to disk. *Finally* refers to point at which liquid leaves disk.

Experimental Equipment and Procedure

Atomizers Studied. The centrifugal disk atomizers used in this study are shown in Figure 1. Their specifications are given in Table 1. These disks were used with four different materials, the physical properties of which are summarized in Table 2.

Disks number 1, 2, 3, 10, 11, and 13, when atomizing Material A with rates of rotation less than 10,000 rev./min., were rotated in a horizontal plane (the fluid being fed from above) by a spindle which was belt-driven by a 2-hp. motor running at 3490 rev./min. Different disk speeds were obtained by changing the drive pulleys. The disk speeds were measured with a Strobotac tachometer. Disk number 12 was rotated by an air turbine. These disks and drives were mounted on a structural steel frame so that the disk was about 6 ft. above the floor as shown schematically in Figure 2. The feed distributor for tests with Material A was specially designed to introduce the feed uniformly around the disk shaft.

For those tests with disk number 10 at rates of rotation greater than 10,000 rev./min. with Materials A, B, and C to determine the effect of viscosity, a 3-hp. variable-frequency motor in a 5-ft. diameter Bowen spray dryer was used. It was necessary to pull air through the dryer to prevent impingement of the spray on the dryer ceiling before spray samples could be obtained.

The other disks (atomizing Material D) numbers 4, 5, 6, 7, 8, and 9 were installed in a spray tower.

Determination of Drop Size and Size Distribution. To determine drop size and drop-size distribution of Materials A, B, and C, samples of the spray were collected and photographed at a given magnification. The resultant drop images were then measured and counted.

To sample the spray either (I) a composite (weighted according to the measured trajectory) of the drops falling on petrolatum-coated glass microscope slides 10 in. below the plane of the disk at 1-ft. intervals in a radial direction from the disk was taken, or (II) a spray sampler as described by Pierce (*26*) and Nukiyama and Tanasawa (*24*) was employed to obtain a sample of the spray on petrolatum- or magnesium smoke-coated slides about 15 in. from the disk. The sampler employed an adjustable clock spring to drive a rotating shutter which exposed the slide to the spray

for a suitable time interval. These two methods appeared to give comparable results (Fig. 3).

The spray was adjusted to the desired operating conditions sufficiently in advance of the sampling to allow the air to become saturated with water vapor. The interval between the collection and photographing of the sample varied from 4 to 8 sec. This time lag was insufficient to cause significant evaporation of drops greater than 40μ in diam. Sprays in which an appreciable fraction of the drops was below 40μ were sampled on magnesium smoke-coated slides (*26*).

Petrolatum-coated slides were prepared by warming a carefully cleaned microscope slide on a heated metal plate, applying a dab of petrolatum which was then spread in a thin even coat with the edge of another slide, and allowing the coating to congeal. Magnesium smoke-coated slides were prepared by exposing a clean microscope slide to the fumes from burning magnesium until a film was deposited which was thicker than the largest drop expected.

Samples were photographed with transmitted light, dark-field illumination, or, in the case of sample caught in magnesium smoke, with low-angle illumination at a total magnification (X 20) for the usual case. Measurements from photographs with transmitted light taken from the side of drops collected on a petrolatum-coated slide indicated that the drops were hemispherical. The actual size of the drop represented by a transmitted light photograph of a drop on a petrolatum-coated slide was, therefore, taken to be 0.8 (ratio of the diameter of a sphere to the diameter of a hemisphere of equal volume) times the measured size of the image divided by the photographic magnification. Photographic images of drops with dark-field illumination were found to be greater than those with transmitted light by 10%. The actual size of the drop represented by a photograph with dark-field illumination was, therefore, taken to be 0.8 times the measured size of the image divided by 1.1 times the photographic magnification. The craters left by drops on magnesium smoke-coated slides were assumed to be the same diameter as the drops forming them. The actual size of the drop represented by a photograph with low-angle illumination was, therefore, taken to be the measured size of the image divided by the photographic magnification.

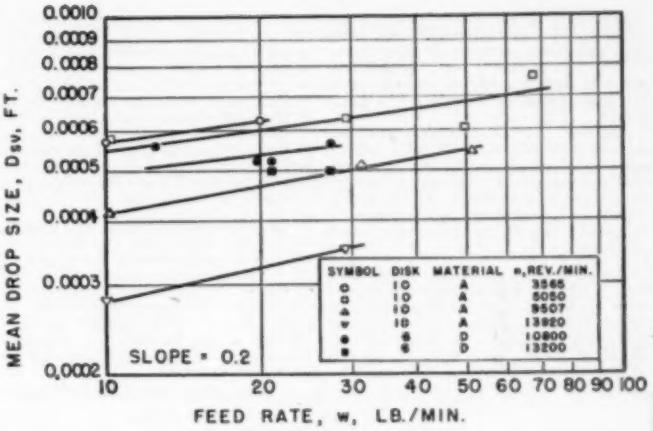


Fig. 4. Effect of feed rate on drop size.

Method I involved sampling of the spray below the disk at different radial distances from the disk centerline. The true drop-size distribution of the spray was calculated by weighting the drop-size distribution of the individual samples proportionally to the fraction of the total spray represented by the sample. This fraction was determined by distribution measurements.

Thus the volume or weight fraction of each size range was obtained for the composite sample. For the sprays sampled by Method II, the number fraction in each size range was obtained. To determine the drop size and drop-size distribution of Material D, samples of the material, which had completely solidified, were screened and the weight fraction greater than the screen openings calculated.

Resulting data were plotted on logarithmic probability paper as drop diameter vs. cumulative per cent greater than a given diameter. They were found to give approximately a straight line. No better fit of these data was obtained to the expression proposed by Nukiyama and Tanasawa (*24*):

$$\frac{d(n_i)}{d(D_i)} = k_1(D_i)^q exp(-m_1 D_i)^q \qquad (10)$$

to the Rosin-Rammler Equation (7) for the number fraction less than size D_i, **T**,

$$\mathbf{T} = exp(-k_2 D_i^{\,r}) \qquad (11)$$

or to the Roller Equation (7) for the weight per cent less than size D_i, **A**,

$$\mathbf{A} = k_3(D_i)^{0.5} exp(-m_3/D_i) \qquad (12)$$

The Hatch-Choate Equations (*12, 13*) were, therefore, taken to represent the drop-size distribution obtained. These equations are summarized in Table 3. Use of this linear logarithmic probability drop-size distribution is convenient because any desired average drop diameter can be readily calculated from any other given average drop diameter if the drop-size dispersion is known. This latter quantity, designated as a, is defined by Hatch and

TABLE 2.—PHYSICAL PROPERTIES OF MATERIAL SPRAYED

Material	Viscosity μ, lb./(ft.)(min.)	Density, ρ, lb./cu.ft.	Surface Tension σ, lb./(min.)^2
A	0.0404	62.4	574
B	48.5	85.6	593
C	364.	88.8	604
D	0.0645	88.0	786

TABLE 3.—HATCH-CHOATE RELATIONSHIPS BETWEEN AVERAGE DROP DIAMETERS

Type of Diameter	Symbol	Mathematical Definition	Equivalent Log Value By Count	Equivalent Log Value By Weight
Geometric count average	D_n	$\text{antilog} \frac{\Sigma n_i \log D}{\Sigma n_i}$	$\log D_n$	$\log D_w - 6.9078 \log^2 a$
Geometric weight average	D_w	$\text{antilog} \frac{\Sigma n_i \log D}{\Sigma n_i}$	$\log D_n + 6.9078 \log^2 a$	$\log D_w$
Arithmetic average	D_{av}	$\frac{\Sigma n_i D}{\Sigma n_i}$	$\log D_n + 1.1513 \log^2 a$	$\log D_w - 5.7565 \log^2 a$
Surface average	D_s	$\left(\frac{\Sigma n_i D^2}{\Sigma n_i}\right)^{1/2}$	$\log D_n + 2.3026 \log^2 a$	$\log D_w - 4.6052 \log^2 a$
Volume average	D_v	$\left(\frac{\Sigma n_i D^3}{\Sigma n_i}\right)^{1/3}$	$\log D_n + 3.4539 \log^2 a$	$\log D_w - 3.4539 \log^2 a$
Specific-surface	D_z	$\left(\frac{\Sigma n_i D^{-1}}{\Sigma n_i}\right)^{-1}$	$\log D_n - 1.1513 \log^2 a$	$\log D_w - 8.0591 \log^2 a$
Surface-per-unit-volume	D_{sv}	$\frac{\Sigma n_i D^3}{\Sigma n_i D^2}$	$\log D_n + 5.7565 \log^2 a$	$\log D_w - 1.1513 \log^2 a$

Where D = individual particle diameter; n_i = number of particles of given diameter if analysis is by count, or weight of particles of a given diameter if analysis is by weight; a = ratio of 50% size to 84.13% size or of 15.87% size to 50% size taken to give a number greater than 1.

Choate (*13*) as the ratio of the 50% size to the 84.13% size or the 15.87% size to the 50% size taken to give a number greater than 1. This coefficient is the log geometric standard deviation and is independent of the type of diameter for which it is calculated.

Because the surface-per-unit-volume average drop diameter is likely to have the most significance in considering phenomena that depend on the amount of surface created, as in atomization, the volume or weight and number fraction in each size range was converted to this diameter using the equations in Table 3.

Measurement of Spray Trajectory. Spray distribution measurements were made with the aid of a wedge-shaped collector (Fig. 2). This collector was fabricated of galvanized sheet iron in the shape of a 16.5° sector of a circle of 7-ft. radius. It was divided into seven compartments with concentric barriers at 1-ft. intervals. Each compartment was provided with a separate drain. The collector was supported in a level position 10 in. below the disk with the apex directly under the center of the disk. The radial distance within which 50% of the spray was collected was taken as a measure of the trajectory of the spray. The amount of material collected generally checked within 10% of that calculated from the feed rate to the disk.

Measurement of Power. The power required for atomization was obtained from the gross power drawn by the atomizer and drive mechanism by correcting for copper losses of the motor and fixed losses (*6*). To measure the copper losses of the three-phase drive motor at various values of the current drawn, the rotor was blocked and the current drawn varied by adjusting three Powerstat autotransformers connected in *Y*. The electrical quantities were measured with a Weston industrial analyzer. The fixed losses were taken to be the no-load power requirements after correction for the copper loss associated with the no-load current. For most of the tests the net power was 50%, or less, of the total power consumed. Thus, at low feed rates, the net power could be in error by as much as 30%.

Experimental Results

Drop Size and Drop-Size Distribution. A total of 67 runs was made employing 13 different disks for which drop size and drop-size distribution were determined. The range of variables investigated were:

TABLE 4.—DROP SIZE AND SIZE-DISTRIBUTION DATA

Disk No.	Material	Feed Rate w, lb./min.	Rate of Rotation n, rev./min.	Drop Diameter D_{vv}, microns	Drop Diameter D_{max}, microns	Hatch's Dispersion a	$(\Gamma/\rho n r^2)(\mu/\Gamma)^{1/2}(\rho a L/\Gamma^2)^{1/6}$	D_{vv}/r
1	*A*	10.0	9,400	89	320	1.46	1.856×10^{-4}	1.87×10^{-2}
2	*A*	10.0	9,000	133	280	1.39	1.082 "	2.10 "
2	*A*	20.8	8,500	133	400	1.39	1.46 "	2.10 "
3	*A*	10.0	7,950	89	200	1.46	0.494 "	0.876 "
3	*A*	20.3	7,050	124	360	1.64	0.710 "	1.22 "
4	*D*	20.0	10,800	155	589	1.43	2.57 "	3.05 "
4	*D*	20.0	10,800	144	589	1.45	2.57 "	2.83 "
4	*D*	25.0	10,800	144	589	1.48	2.76 "	2.83 "
4	*D*	19.2	10,800	118	590	1.57	2.52 "	2.32 "
4	*D*	26.3	10,800	130	590	1.62	2.795 "	2.56 "
4	*D*	22.5	1,200	776	2000	2.04	24.2 "	15.25 "
4	*D*	22.5	6,000	246	840	1.55	4.86 "	4.85 "
4	*D*	22.5	8,400	165	2000	1.51	3.46 "	3.25 "
4	*D*	22.5	10,800	128	2000	1.66	2.69 "	2.52 "
4	*D*	20.8	10,800	154	590	1.56	2.60 "	3.03 "
4	*D*	21.2	8,400	208	840	1.47	3.36 "	4.09 "
5	*D*	25.0	8,400	149	417	1.44	2.25 "	2.35 "
5	*D*	26.7	1,200	606	1168	1.96	11.4 "	9.56 "
5	*D*	26.7	6,000	184	589	1.48	3.22 "	2.90 "
5	*D*	26.7	10,800	123	589	1.32	1.79 "	1.94 "
6	*D*	27.4	3,600	412	2000	1.70	31.1 "	13.50 "
6	*D*	27.4	8,400	190	840	1.56	10.33 "	6.00 "
6	*D*	27.4	10,800	172	840	1.54	8.04 "	5.42 "
6	*D*	19.7	10,800	159	840	1.64	7.25 "	5.01 "
6	*D*	27.4	13,200	152	590	1.51	6.59 "	4.79 "
6	*D*	12.5	10,800	171	590	1.44	4.26 "	5.38 "
6	*D*	21.0	10,800	159	590	1.45	7.39 "	5.01 "
6	*D*	21.0	13,200	153	590	1.45	6.06 "	4.81 "
6	*D*	21.0	18,000	134	590	1.43	4.43 "	4.23 "
7	*D*	30.0	6,000	171	833	1.43	2.46 "	2.33 "
7	*D*	41.6	1,200	479	1651	1.88	13.7 "	6.55 "
7	*D*	41.6	860	576	1651	1.95	19.13 "	7.89 "
8	*D*	41.6	1,200	400	1651	1.55	9.45 "	3.91 "
8	*D*	50.0	1,200	446	1651	1.58	10.1 "	5.84 "
8	*D*	58.4	1,200	518	1651	1.58	10.6 "	6.64 "
8	*D*	50.0	860	527	1651	1.62	14.05 "	6.75 "
9	*D*	22.5	1,200	561	840	1.73	10.43 "	11.05 "
9	*D*	22.5	6,800	219	840	1.54	3.89 "	4.31 "
9	*D*	22.5	8,400	170	2000	1.42	2.78 "	3.34 "
9	*D*	22.5	10,800	142	840	1.35	2.16 "	2.79 "
9	*D*	21.2	1,200	656	2000	1.80	19.02 "	13.9 "
10	*A*	31.3	5,060	205	600	1.61	2.64 "	3.14 "
10	*A*	10.4	5,080	177	480	1.58	1.83 "	2.71 "
10	*A*	51.2	9,310	166	400	1.47	1.78 "	2.54 "
10	*A*	31.3	9,510	156	360	1.44	1.405 "	2.39 "
10	*A*	10.4	9,700	127	280	1.41	0.957 "	1.94 "
10	*A*	29.2	13,850	107	240	1.35	0.946 "	1.64 "
10	*A*	10.0	14,060	92	200	1.36	0.656 "	1.31 "
10	*A*	20.0	3,550	192	360	1.69	3.35 "	2.94 "
10	*A*	10.0	3,530	175	440	1.67	2.57 "	2.68 "
10	*A*	10.0	6,710	126	220	1.48	1.37 "	1.93 "
10	*A*	49.5	5,040	184	640	1.76	3.11 "	2.82 "
10	*A*	67.5	5,020	233	800	1.66	3.45 "	3.57 "
10	*A*	29.2	5,060	193	400	1.60	2.40 "	2.96 "
10	*B*	5.1	14,000	256	520	1.39	4.29 "	3.92 "
10	*C*	1.7	14,000	228	360	1.37	2.62 "	3.49 "
11	*A*	20.0	9,520	170	324	1.42	1.99 "	2.68 "
11	*A*	10.0	9,600	127	252	1.39	1.57 "	2.00 "
11	*A*	59.1	3,550	405	683	1.53	16.5 "	6.39 "
11	*A*	10.0	3,565	294	647	1.51	4.2 "	4.63 "
12	*A*	2.2	7,500	196	180	1.70	8.85 "	7.71 "
12	*A*	1.3	7,700	177	360	1.69	7.17 "	6.96 "
12	*A*	1.3	14,200	85	360	1.55	3.90 "	3.36 "
12	*A*	0.55	7,400	134	252	1.48	5.58 "	5.28 "
12	*A*	2.2	11,300	96	220	1.57	5.85 "	3.79 "
12	*A*	0.79	12,500	106	114	1.76	3.74 "	4.17 "
12	*A*	0.79	12,500	69	125	1.61	3.74 "	2.74 "

Γ = 1.5 to 90 lb./(min.)(ft.)
n = 860 to 18,000 rev./min.
r = 0.033 to 0.333 ft.
L = 0.026 to 1.61 ft.
Z = 1, 2, and 24
ρ = 62.4 to 88 lb./cu.ft.
σ = 74 to 100 dynes/cm.
μ = 1 to 9,000 cp.

These data are summarized in Figures 4-9 and Table 4. The drop-size distribution obtained at various times for one operating condition is given in Figure 3.

Trajectory. The trajectory of water spray from three disks was measured for 25 runs. The range of variables covered was:

w = 0.55 to 73.7 lb./min.
n = 4750 to 12,500 rev./min.
r = 0.083 to 0.214 ft.
L = 0.524 to 1.31 ft.
Z = 1 and 24.

These data are summarized in Figure 10 and Table 5.

Power Requirements. The power required to atomize water from three different disks was measured. A total of 64 determinations was made. The range of variables studied was:

w = 10.4 to 84.2 lb./min.
n = 3310 to 9700 rev./min.
r = 0.208 to 0.229 ft.
L = 0.031 to 1.44 ft.
Z = 1 and 24.

These data are summarized in Figure 11 and Table 6.

Comment on Experimental Results

Drop Size. The drop size (expressed as surface-per-unit volume average diameter) produced by centrifugal disks was found to vary directly as the feed rate, w or Γ, to the 0.2 power. This was established by 16 runs as shown in Figure 4. This effect appears to be independent of the other variables for the six conditions tested within the precision of the data.

The drop size was found to vary (as an average (inversely as the 0.6 power of disk speed, n. This was established by 16 runs as shown in Figure 5. The effect of n is probably independent of the other variables for the six conditions tested.

Viscosity, μ, was found to affect drop size directly as the 0.2 power. This was established by four runs as shown in Figure 6. Since it was not varied independently, the drop size produced was corrected for n and w to obtain the correlation. The variation in ρ and σ was 42 and 11% respectively; whereas the variation in μ was 900,000%. The inability to correct for ρ and σ at this time, therefore, should have an insignificant effect on the results. Unfortunately, r and L were not varied, and n varied insignificantly. The success of the final correlation has indicated that

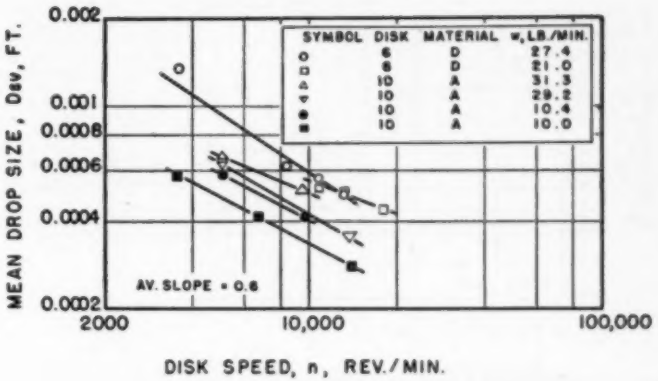


Fig. 5. Effect of disk speed on drop size.

the effect of μ may be independent of the other variables over the practical range.

Measurements of the drop size produced by three similar radially vaned disks of three different radii indicate that drop size may increase to a maximum as the radius increases, then decrease as shown by Figure 7 on which average data for 45 runs are plotted. However, insufficient data are available to establish definitely the effect of radius on drop size. Drop size was taken to vary inversely as the radius to the 0.2 power since this value was in agreement with the dimensional analysis.

The effects of the other disk parameter (wetted periphery), density, and surface tension of the fluid were determined from the dimensional analysis to

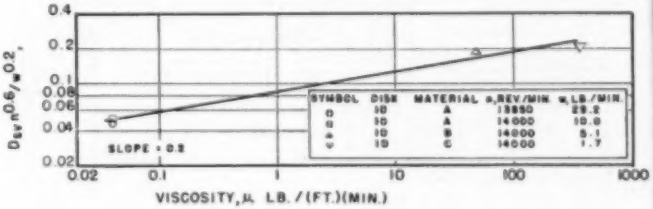


Fig. 6. Effect of viscosity on drop size.

TABLE 5.—TRAJECTORY OF SPRAY

Disk No.	Material	Rate of Rotation n, rev./sec.	Feed Rate w, lb./min.	Distance in Which 50% of Material Has Dropped Less Than 10 in. Below Disk, z_{50}, ft.	rn_{50} (ft.)(rev./min.) (lb./min.)
1	A	3600	9.2	3.35	4840
10	A	5080	10.4	3.65	11300
10	A	9700	10.4	3.75	21600
10	A	6410	10.7	4.15	14700
10	A	6380	13.2	4.5	18000
10	A	5060	31.3	5.4	33800
10	A	9510	31.2	5.6	63500
10	A	9310	51.2	6.15	102000
10	A	4750	73.7	4.7	75000
10	A	5100	4.2	2.9	4580
10	A	5090	6.2	3.25	6750
10	A	6480	4.2	3.4	5820
10	A	6460	5.5	3.55	7620
11	A	5100	4.2	2.05	4450
11	A	5090	6.2	2.4	6550
11	A	5080	8.3	2.85	8760
11	A	5080	10.4	2.75	11000
11	A	5070	12.5	2.8	13200
11	A	5060	14.6	2.8	15400
11	A	5050	16.6	2.85	17400
11	A	5040	18.7	2.85	19600
12	A	7400	0.55	2.15	338
12	A	7500	2.24	2.4	1400
12	A	7700	1.32	2.05	850
12	A	11300	2.24	2.5	2110
12	A	12500	0.79	2.3	824

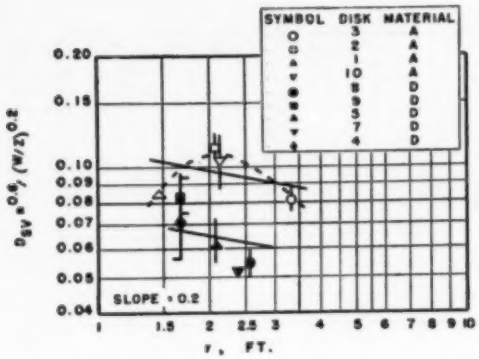


Fig. 7. Effect of disk radius on drop size.

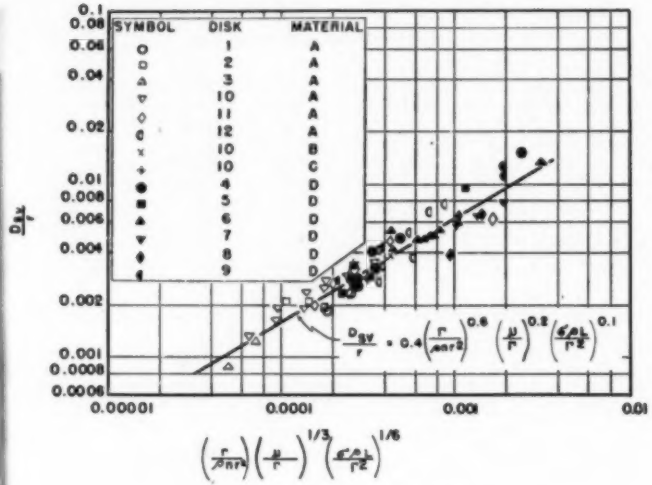


Fig. 8. General correlation of drop size.

be the inverse 0.1 power, inverse 0.5 power, and direct 0.1 power respectively. This is borne out by the general correlation shown in Figure 8 which can be represented by:

$$\frac{D_{sv}}{r} = 0.4\left(\frac{\Gamma}{\rho n r^2}\right)^{0.6}\left(\frac{\mu}{\Gamma}\right)^{0.2}\left(\frac{\sigma \rho L}{\Gamma^2}\right)^{0.1} \qquad (13)$$

This compares with Equation (9) when the constants a, b, c, and f are -0.2, 0.6, -0.1 and -0.1 respectively and K is 0.4.

Drop-Size Distribution. The Hatch dispersion coefficient, α, was selected as the parameter for expressing drop-size distribution because it was observed that the drop-size distribution plotted approximately as a straight line on logarithmic probability paper. From the 67 runs analyzed, it was determined that the Hatch dispersion coefficient, α, varied approximately as the 0.1 power of the surface per-unit-volume average drop diameter as shown in Figure 9. This can be expressed as:

$$\alpha = 3.3(D_{sv})^{0.1} \qquad (14)$$

This equation has no theoretical basis. It will probably give only an approximation of drop-size distribution. The dispersion coefficient varied only over a twofold range in the tests made. No significant variation with any operating variable was noted, other than that an increased drop size seemed to give increased dispersion.

Since the Hatch-Choate relationships assume a linear logarithmic probability relation, small variations in drop-size distribution at either the very fine or coarse sizes have not been considered. It is entirely possible that a small fraction of the drops might have their distribution varied markedly by changes in operating variables or disk design. More extensive tests would be required to establish this fact.

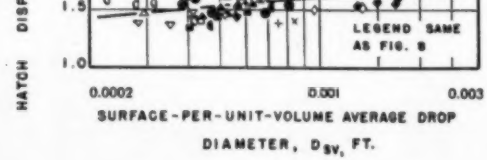


Fig. 9. Variation of drop-size distribution with drop size.

Trajectory. The trajectory of the spray, as measured by the distance 50% of the material is thrown before dropping 10 in., is plotted as a function of peripheral disk velocity, rn, and feed rate, w, in Figure 10 for 26 runs. It is observed that trajectory varies directly as the ¼ power of rnw according to the equation

$$x_{10} = 0.4(rnw)^{1/4} \qquad (15)$$

Insufficient tests were run to establish trajectory for other distances below the disk. Likewise the effect of containing walls was not evaluated. However, it is believed that the relationship will be valid for predicting the effect of changed conditions on a trajectory already established experimentally.

Power. From consideration of the transfer of momentum from the disk to the liquid, the net power, P, required for atomization has been calculated to be $w(2\pi rn)^2/g_c$ as given in Equation (5). As shown in Figure 11 this equation was confirmed by 24 measurements of the power required with water for one vaned disk (No. 10).

For disks on which slip of the liquid is possible, the power requirements are not as great. The amount of slip would be expected to be a function of the Reynolds number. Data from 40 runs on Disk 11 and 12 are plotted in Figure 11 as the fraction of theoretical power vs. Γ/μ, which is one fourth of the Reynolds number. The slip apparently increases at a greater rate at Reynolds numbers greater than 2400 to 3200 ($\Gamma/\mu = 600$ to 800) which is the range

in which flow normally changes from the viscous to the turbulent type.

A more complete analysis of the power requirements may show some effect of the point of introduction of the feed and the direction of film movement relative to the direction of the centrifugal force which the data available at present do not.

Comparison with Data of Other Investigators

Drop Size. Only a limited amount of data is available which can be compared directly with the relationship established in Figure 8. These data include that of Adler and Marshall (*1*) and Hinze and Milborn (*15*). By measuring the average drop sizes from photographs of drops of glycerol published by Bär, and by assuming the feed rate, his data can also be used. A comparison is shown in Figure 12. Data of all the investigators seem to give approximately the same slope when plotted similarly to Equation (13). Hinze and Milborn obtained a substantially smaller drop size than would have been predicted while Adler and Marshall obtain a greater average drop size. These differences may be entirely due to the experimental techniques employed. The discrepancy of Bär's data is partially due to the assumption of the feed rate employed.

None of the equations which have been proposed for the drop size from centrifugal disks predicts an effect of feed rate or viscosity. Both these quantities were found to affect the average drop size to a certain extent. The relationships proposed by Bär (*3*), Muraszew (*23*), Walton and Prewett (*33*) Equations (1) and (3) predict that the drop size should vary inversely with the first power of the rate of rotation and the 0.5 power of the disk radius and fluid density and directly with the 0.5 power of surface tension. It was found in this work that the average drop size varied inversely with the 0.6 power of the rate of rotation, 0.2 power of disk radius, 0.5 power with fluid density and directly with the 0.1 power of the surface tension. Thus it would appear that, for the average drop diameter at least, these equations are not valid in the realm of operation covered by this work.

Likewise the equations deduced by Bär, Muraszew, and Hinze, assuming that the impact with the surrounding atmosphere causes atomization, give no better prediction of the effect of the operating variables. These relationships (Equations (2), (4), and (8)) predict that the diameter should vary inversely with the square of the rate of rotation and disk radius and directly with the surface tension. This is even further in error than Equations (1) and (3). For this reason it is expected, at least under the conditions of this investigation, that impact with the surrounding atmosphere is not the principal cause of atomization.

To investigate the possibility that maximum drop size might be predicted accurately by the relationship of Walton and Prewett, the experimental data were checked against Equation (3). The drop size predicted by this equation was always smaller than the maximum drop size observed by a factor of two to ten. It therefore appeared that at practical feed rates this relationship was not even valid for predicting maximum drop size.

Although Walton and Prewett did not list their feed rate, it was obtained for methylsalicylate from their Figure 7. Using these data the expression employed in the abscissa of Figure 8 was calculated. The ratio of maximum drop size to disk radius both for their data and those presented herein was plotted in a manner similar to Figure 8. These are shown in Figure 13. A good approximation of all the data is given by the equation:

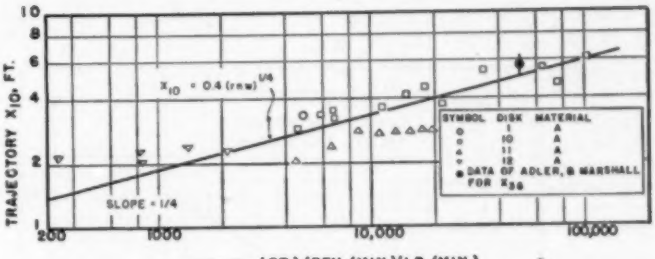


Fig. 10. Trajectory of spray.

$$\frac{D_{max}}{r} = 1.2\left(\frac{\Gamma}{\rho\omega r^3}\right)^{0.6}\left(\frac{\mu}{\Gamma}\right)^{0.2}\left(\frac{\rho a L}{\Gamma^2}\right)^{0.1} \quad (16)$$

This indicates that the maximum drop size to be expected in any spray is approximately three times the surface-per-unit-volume average drop size as calculated by Equation (13).

The scatter of the data given in Figure 13

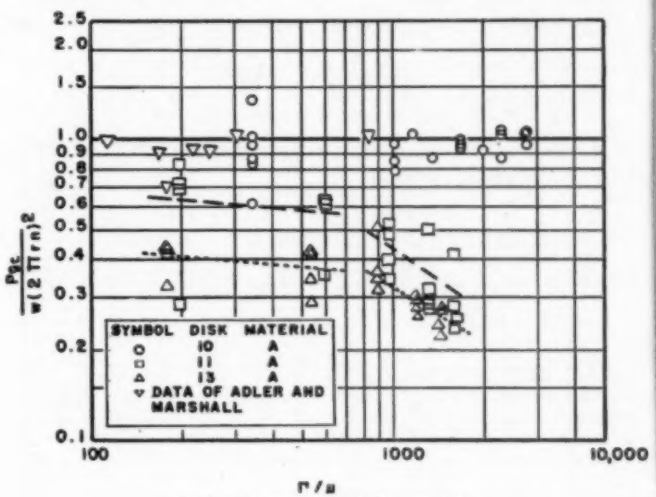


Fig. 11. Net power required for spray disk.

TABLE 6.—POWER-REQUIREMENTS DATA

DISK: 10, MATERIAL: A

Feed Rate w, lb./min.	Disk Speed n, rev./min.	Net Power P, ft.lb./min.	$\frac{Pg_c}{w(2\pi rn)^2}$	Γ/μ
10.4	5050	3.54×10^3 "	0.868	343
31.3	4910	10.7 "	0.964	1033
51.3	4850	17.7 "	1.000	1690
69.5	4610	23.4 "	1.072	2295
84.3	4480	26.5 "	1.063	2780
10.4	9000	12.7 "	1.023	343
31.3	7500	20.6 "	0.793	1033
35.4	6150	20.6 "	1.045	1170
10.4	3490	1.15 "	0.615	343
31.3	3455	4.70 "	0.955	1033
51.2	3410	8.37 "	0.957	1690
69.5	3355	12.3 "	1.050	2295
83.7	3310	14.6 "	1.072	2760
10.4	6400	6.16 "	0.964	343
31.3	6150	17.0 "	0.977	1033
51.2	5840	25.0 "	0.977	1690
69.5	5385	26.0 "	0.870	2295
84.3	4760	27.2 "	0.965	2780
10.4	5080	5.31 "	1.357	343
10.4	9700	12.7 "	0.883	343
31.3	9510	40.0 "	0.970	1033
41.0	9590	48.1 "	0.871	1354
51.2	9310	61.4 "	0.940	1690
69.4	9200	68.8 "	0.915	1990

(Table 6 continued on page 190)

could be attributed to the fact that no attempt was made to measure the maximum drop size during the course of active work. It was obtained later from drop photographs and screen analyses. Agglomeration in both cases and lack of an actual physical measurement in the screen analyses may tend to cause the scattering of the data.

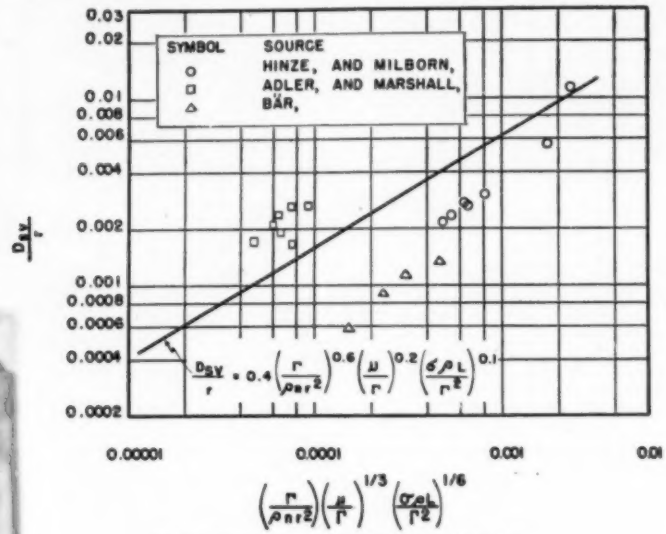


Fig. 12. Comparison with literature data on drop size.

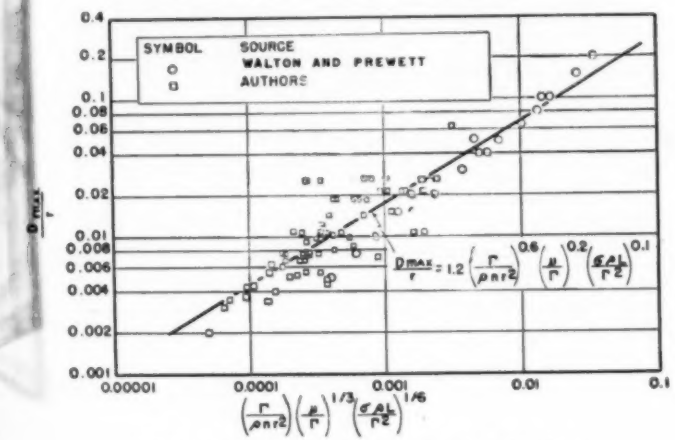


Fig. 13. Comparison with literature data on maximum drop size.

Drop-Size Distribution. Bär, and Walton and Prewett suggested that spray from centrifugal disks does not contain random drops of all sizes but consists of a number of large and a number of smaller drops. This was not found to be true of the sprays produced in this work, probably because the flow rates employed were always much greater than those used by other investigators. Data of Hinze and Milborn indicated that random drops of all sizes were obtained. Although the Hatch coefficient was not calculated for their data, they found increasing dispersion with increasing drop size.

Trajectory. Equations put forth by Lapple and Shepherd (*16*) for calculating the trajectory of particles in air were found inapplicable for the cases encountered in this work because of the air flow induced by the spray.

Adler and Marshall (*1*) gave the distance 50% of the spray is thrown before dropping 36 in. for seven disks operating at the same peripheral velocity and feed rate. This point is plotted on Figure 10. As might be expected, they show somewhat greater trajectory for the plane 36 in. below the disk than was found 10 in. below the disk.

Power. Adler and Marshall gave the net power required by seven disks for one feed rate and one peripheral velocity. These data are plotted on Figure 11. Their data confirm the theoretical equation within practical limits.

Inasmuch as Philips (*25*) did not specify the dimensions of the disks for which power data were reported, it was impossible to compare his data directly with Equation (5). Nominally, however, the effects of disk speed and feed rate are similar to those predicted by this equation.

Summary

From these data, expressions have been developed which can form the basis for rational design and operation of centrifugal atomizing disks over the usual range of operating conditions. Within the range of variables covered by this investigation, the accuracy of the equations can be expected to be ±30% or better. This is believed to be sufficient for almost all design purposes.

There was no indication that special disk designs imparted special properties.

TABLE 6.—POWER-REQUIREMENTS DATA—*Continued*

Disk: 11, Material: *A*					Disk: 13, Material: *A*				
Feed Rate *w*, lb./min.	Disk Speed *n*, rev./min.	Net Power *P*, ft.lb./min.	$\frac{Pg_c}{w(2\pi rn)^2}$	Γ/μ	Feed Rate *w*, lb./min.	Disk Speed *n*, rev./min.	Net Power *P*, ft.lb./min.	$\frac{Pg_c}{w(2\pi rn)^2}$	Γ/μ
10.4	5040	2.65	0.683	197	10.4	5050	1.99	0.418	179
31.3	4965	7.04	0.616	592	31.3	5010	5.90	0.419	540
51.2	4950	7.30	0.394	970	51.2	4955	8.15	0.362	884
69.5	4940	7.92	0.317	1318	69.5	4940	9.17	0.302	1200
83.7	4925	8.36	0.280	1585	84.2	4920	10.2	0.279	1451
10.4	6520	4.65	0.713	197	10.4	6550	3.54	0.441	179
31.3	6340	11.7	0.630	592	31.3	6400	9.75	0.425	540
51.2	6200	16.1	0.555	970	51.2	6270	13.7	0.523	884
69.5	6100	19.2	0.503	1318	69.5	6250	14.3	0.294	1200
84.2	6100	18.9	0.417	1595	84.2	6215	15.8	0.271	1451
10.4	3490	0.531	0.284	197	10.4	3505	0.754	0.329	179
31.3	3480	1.99	0.356	592	31.3	3485	2.34	0.343	540
51.2	3470	3.10	0.341	970	51.2	3475	3.54	0.319	884
69.5	3465	3.41	0.275	1318	69.5	3470	3.89	0.259	1200
84.9	3460	3.89	0.259	1608	82.5	3470	3.94	0.222	1422
10.4	9150	10.8	0.837	197	10.4	9240	7.05	0.431	179
31.3	8580	21.2	0.624	592	31.3	9250	13.8	0.288	540
51.2	7780	22.3	0.489	970	51.2	8450	22.6	0.345	884
69.5	7270	15.5	0.285	1318	69.5	8100	23.0	0.279	1200
84.2	7270	15.5	0.236	1595	81.5	8080	20.8	0.244	1405

to the sprays formed by them. It is believed that simple cup-shaped or vaned disks will prove adequate for almost all operations.

Notation

a = constant
b = constant
c = constant
d = differential operator
D = individual drop diameter, ft.
D_a = surface-area average drop diameter, ft.
D_{av} = arithmetic-mean average drop diameter, ft.
D_i = median diameter of size range i, ft.
D_{max} = maximum drop diameter, ft.
D_n = geometric-mean average drop diameter by count, ft.
D_s = specific-surface average drop diameter, ft.
D_{sv} = surface-per-unit volume average drop diameter, ft.
D_v = volume average drop diameter, ft.
D_w = geometric-mean average drop diameter by weight, ft.
f = constant
g_c = conversion factor, 116,000(lb.)(ft.)/(lb. force)(min.)(min.)
k_1 = constant
k_2 = constant
k_3 = constant
K = proportionality constant
L = wetted periphery of disk/stream, ft.
m_1 = constant
m_2 = constant
m_3 = constant
N_{We} = Weber Number
n = rate of rotation of disk, rev./min.
n_i = number of drops in size range i in a sample
p = constant
P = net power required for atomization, ft.-lb./min.
P_h = net power required for atomization, hp.
q = constant
r = radius of disk, ft.
s = constant
V = velocity, ft./min.
w = feed rate of liquid atomized, lb./min.
x_{10} = distance 50% of spray is thrown before dropping 10 in. from plane of disk, ft.
x_{36} = distance 50% of spray is thrown before dropping 36 in. from plane of disk, ft.
Z = number of liquid streams per disk

GREEK SYMBOLS:

α = dispersion coefficient, (50% size)/(84.13% size)
β = direction of liquid movement on disk, angle from radius, degrees
Γ = feed rate of liquid atomized, based on wetted periphery, lb./(min.)(ft.)
θ = direction of liquid movement on disk, angle from vertical, degree
Λ = cumulative weight per cent smaller than size D in Roller Equation (12)
μ = viscosity of feed, lb./(ft.)(min.)
π = ratio of circumference to diameter of circle, 3.1416
ρ = density of feed, lb./cu.ft.
ρ_g = density of gas around disk, lb./cu.ft.
σ = surface tension of feed, lb./(min.)(min.)
Σ = mathematical operator indicating summation
ϕ = air-resistance coefficient
Υ = number fraction less than size D in Rosin-Rammler Equation (11)

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Discussion

B. A. Smith (Koppers Co., Inc., Pittsburgh, Pa.): Has anything ever been done by means of two contrarotating atomizing disks one within the other?

F. A. Gluckert: Not to my knowledge. However, some spray dryers employ disks with concentric sets of vanes which rotate as a unit.

B. A. Smith: In breaking up soft, lumpy materials, the old principle of the double squirrel-cage disintegrator is pretty well known and it does a fair job of breaking up soft lumps. You might consider particles of liquid as soft lumps and thereby get a better breakup by making a contrarotation of the external disk.

F. A. Gluckert: The proposal may have some possibilities particularly for heavy materials—viscous materials or slurries that are practically solid. We have experienced no difficulty in obtaining atomization if we could pump the material to the disk.

(Presented at A.I.Ch.E. Forty-third Annual Meeting, Columbus, Ohio.)

THE APPLICATION OF RADIOACTIVE TRACERS TO DIFFUSIONAL OPERATIONS

Binary and Ternary Equilibrium Data

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University of Kansas, Lawrence, Kansas

The purpose of the present research has been to demonstrate the applicability of carbon-14 to chemical engineering investigations, particularly in the field of the diffusional operations; and also, if possible, to develop simpler methods of assaying liquid samples containing the isotope.

Four major investigations were carried out. All four were related to the principal objective, but each had its own well-defined aims and problems. The first investigation resulted in the successful development of a new device for "counting" the radioactive emissions from liquid samples which contain carbon-14. Two types of this device, one counter for use upon static samples, and one capable of continuously monitoring a liquid stream, were developed. In the second study a modified Othmer still was used to obtain vapor-liquid equilibrium data on the systems methanol-water and methanol-ethanol. The analysis for methanol was made using methanol tagged by carbon-14. The methanol-water study demonstrated the applicability of the tracer method to this type of investigation. The next application of the tracer technique was to liquid-liquid equilibrium data. The system methanol-*n*-butanol-water was studied at 30° C. and at a pressure of one atmosphere; radioactive methanol counts and density determinations were used for sample analyses. Complete component distribution and solubility data were obtained. Finally, the tracer technique was applied to a study of a ternary system, methanol-ethanol-water, in a fractionation column. This fourth study will be the subject of a subsequent paper.

WHILE new materials and new techniques which are of interest to the chemical engineer appear with increasing frequency, a development seldom occurs as different in kind and as versatile in application as the recent production in significant quantities of radioactive isotopes. The phenomenon of radioactivity (the emission of energy and/or mass from unstable atomic nuclei) has been recognized for more than half a century, but before 1945 the supply of radioactive isotopes in appreciable concentration was limited to small quantities of some of the naturally occurring heavy metals such as radium and thorium. The advent of the chain-reacting uranium pile has made possible the production in relatively large quantities of radio-isotopes of most of the elements. These materials are available for use by anyone who can fulfill reasonable requirements of ability and intent.

One of the most important of these radio-isotopes is carbon-14, a heavy isotope of carbon. The familiar stable isotope of carbon, carbon-12, occurs in large proportion in petroleum products, in animal and vegetable matter, in coal tars and their derivatives, and in many drugs and medicines. Carbon-14 may be incorporated into many of these sub-

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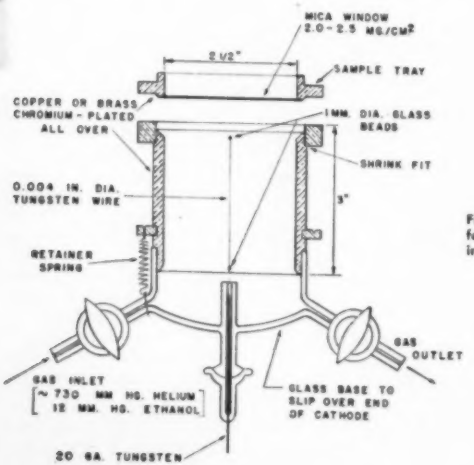


Fig. 1. Geiger counter for weak beta emitters in volatile liquid samples.

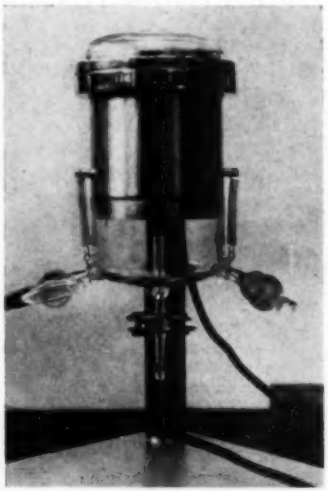


Fig. 2. Static-sample counter.

stances, and the material thus "tagged" with a radioactive atom may be used in numerous types of investigations. Although there are many difficulties in preparing tagged carbon molecules, more than 50 such compounds are available. Carbon-14 is converted to ordinary nitrogen on the emission of beta particles (high-speed electrons) and has a half-life of about 5000 years. Consequently, compounds containing carbon-14 will remain in storage for long periods of time without losing any appreciable quantity of radioactivity. Carbon-14 has already been utilized in a number of chemical and biological studies, but its application to problems of special interest to the chemical engineer has been neglected—perhaps because of certain difficulties in the quantitative measurement of the isotope.

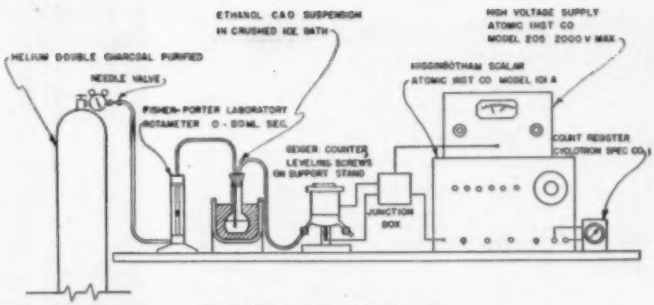


Fig. 3. Counting assembly schematic.

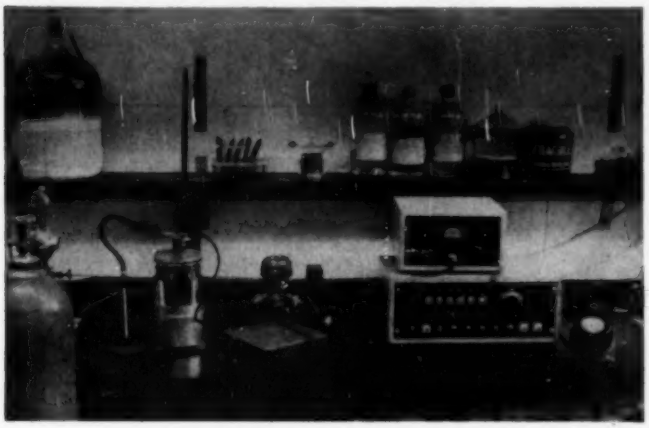
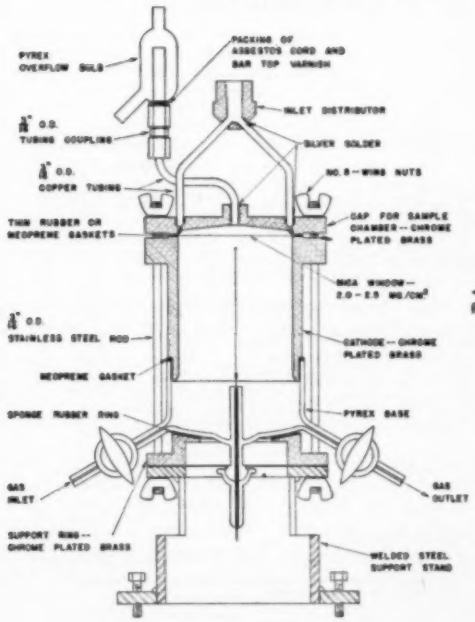


Fig. 4. Counting assembly.



◀ Fig. 5. Continuous-flow sample counter assembly.

Method for Counting Carbon-14 in Volatile Liquids

To illustrate the principle of the tracer method, a simple physical process will be used. A sample of pure methanol is prepared in such a way that some of the molecules have a radioactive carbon atom rather than an ordinary one. This proportion can be determined by a counting method. If a known mass of this methanol is mixed with known masses of benzene and water, some of the methanol will dissolve in the benzene and the remainder will be dissolved in the water. Two liquid phases will result. If the mass of each of the two phases is determined and the total radio-

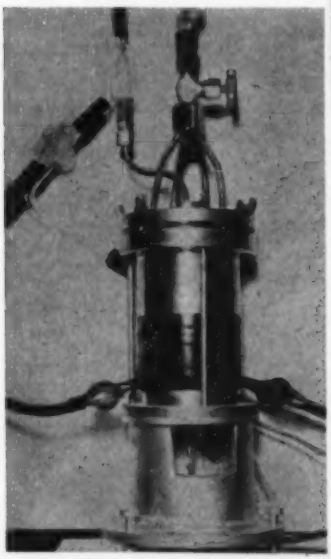


Fig. 6. Continuous-flow sample counter.

TABLE 1.

DAILY COUNTS ON "STANDARD" METHANOL SAMPLE

Data: Tube Design Figure 1

Anode Voltage = 1800 volts

Discriminator Setting = 10 volts

Preamplifier between tube and scalar

Window Thickness = 2.21 mg./cm.^{2}

Nuclear Activity of Sample = 2.08×10^{-4} mc./gm.

Date	Background (Counts/sec.)	Corr. Rate of Sample (Counts/sec.)	% Deviation from Initial Value	% Deviation from Average Value
Aug. 10	2.10	104.16	--	+1.2
11	2.51	104.05	-0.1	+1.1
12	2.61	103.84	-0.3	+0.9
13	2.18	104.97	+0.8	+2.0
15	2.64	102.79	-1.3	-0.1
16	2.33	103.45	-0.7	+0.5
17	2.23	104.90	+0.7	+1.9
18	3.19	100.70	-3.3	-2.2
22	2.62	99.46	-4.5	-3.4
23	2.64	101.68	-2.4	-1.2
24	2.28	101.81	-2.3	-1.1
25	2.14	103.04	-1.1	+0.1
26	2.39	103.23	-0.9	+0.3
	Av. = 2.45	Av. = 102.93		

Av. abs. deviation from initial value = 1.5%

Av. abs. deviation from av. value = 1.2%

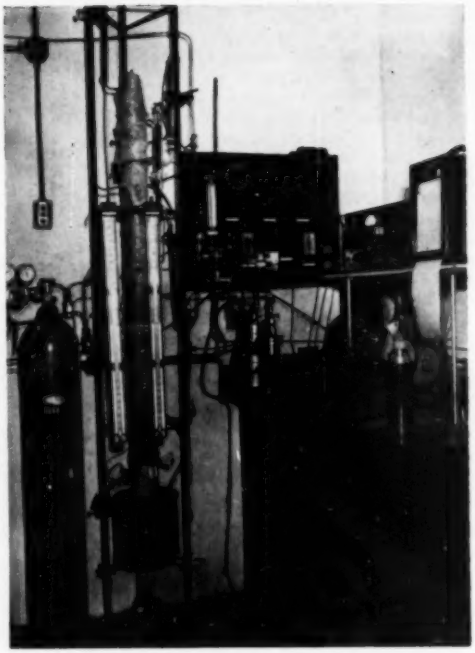


Fig. 7. Continuous-flow counter installed on distillation column.

activity in each phase established by counting a sample from each, the quantity of methanol which has dissolved in each phase can be obtained by calculating a material balance. It was necessary to develop a rapid method of analyzing for carbon-14 by counting. Any device for analyzing for carbon-14 takes advantage of the ionization caused in a material by the passage of the beta rays from the carbon-14. Geiger counters and ionization chambers measure this ionization. Almost all of the methods for carbon-14 assay which have been reported to date involve the oxidation of the carbon to carbon dioxide.

The usual procedure is to absorb the carbon dioxide in caustic soda or caustic potash, to precipitate the carbon as barium

TYPICAL SHEET USED FOR RECORDING AND CALCULATING COMPOSITION BY TRACER ANALYSES

A: BACKGROUND AND STANDARD SAMPLE COUNT

Date Feb. 21, 1951 Disc. Set +10 volts Starting Voltage 1550

BACKGROUND BEFORE COUNTING STANDARD SAMPLE

Window: 1.97 mg./cm.^{2}			Disc. Set +10 volts		Op. Volts 1800	
Start	Finish	Net	Scalar	Time-unit	Rate (C/S)	Remarks
5978	6031	53	22/64	1200 sec.	2.04	

Average

STANDARD SAMPLE--See Notebook No. 6 page 50

Level Tube =		Window 1.97 mg./cm.^{2}		Disc. Set +10 volts	Op. Volts 1800	
Start	Finish	Net	Scalar	Time-unit	Rate (Gross C/S)	Remarks
6033	6238	205	5/64	120 sec.	109.38	
6238	6443	205	40/64	120 sec.	109.67	
6446	6651	205	9/64	120 sec.	109.41	

Average: 109.49

Coincidence Correction: Corr. Rate = $\frac{C}{1 - TC}$ + B

$T = 6.9 \times 10^{-6}$	TC = 0.0755	1 - TC = 0.9245	C/(1 - TC) = 118.43
B = 2.04	Corr. Rate = 115.59	Reference Rate = 111.66	Date of Ref. 12/5/50

Tube Factor = $\frac{\text{Ref. Rate}}{\text{Corr. Rate}} = \frac{111.66}{115.59} = 0.9660$

C = Average gross counts/sec.

T = Resolving time of circuit, sec.

B = Background counts/sec.

Reference rate is the corrected counts/sec. obtained on the standard sample on the date specified.

B. BACKGROUND AND SAMPLE COUNT

Date Feb. 21, 1951 Disc. Set +10 volts Starting Voltage 1630

BACKGROUND BEFORE COUNTING SAMPLE

Window: 2.60 mg./cm.^{2}			Disc. Set +10 volts		Op. Volts 1800	
Start	Finish	Net	Scalar	Time-unit	Rate (C/S)	Remarks
6662	6691	30	34/64	1200 sec.	2.11	

Average

SAMPLE COUNTS -- Do not count samples until background and standard sample counts have been made on same date.

Date: Feb. 21	Series: Methanol-Ethanol Binary	Run No. 1	Sample: 96ill Pot

Level Tube =		Window 2.60 mg./cm.^{2}		Disc. Set +10 volts	Op. Volts 1800	
Start	Finish	Net	Scalar	Time-unit	Rate (Gross C/S)	Remarks
6692	6862	170	37/64	120 sec.	90.98	
6863	7031	168	57/64	120 sec.	90.08	
7032	7198	166	30/64	120 sec.	88.78	
7198	7367	169	26/64	120 sec.	90.35	
7367	7534	167	63/64	120 sec.	89.59	

Average: 89.96

Coincidence Correction $\text{Corr. Rate} = \frac{E}{1 - TC} - B$

$T = 6.9 \times 10^{-6}$	TC = 0.0621	1 - TC = 0.9379	C/(1 - TC) = 95.92
B = 2.11	Corr. Rate = 93.81	Tube Factor = 0.9660	Corr. Rate = Tube F. = 90.62

Tracer Rate* on same Window = 92.21 Wt. % Tracer = 98.28%

*This rate after correction for coincidence, background, and moisture or other inert material in tracer.

TABLE 2.

TABLE 3.

PHYSICAL PROPERTIES OF LIQUIDS EMPLOYED IN EQUILIBRIUM STUDIES

Material	Source & Grade	Boiling Pt. °C, 760 mm. Hg	Specific Gravity d_4^{20}	Refractive Index n_D^{20}
Methanol	Mallinckrodt Anal. Reag.	64,65	0,7915	1,3283
Ethanol	Commercial Solv. Redistilled	78,28	0,7897	1,3612
Water	Laboratory Distilled	100,05	*	**
n-Heptane	Phillips Pure Grade Redistilled	98,4	0,6946	1,3876
Methylcyclohexane	Phillips Pure Grade Redistilled	101,0	0,7703	1,4227

* Used as standard for pycnometer calibration (d_4^{20} = 0,99823)
** Used as standard for refractometer calibration (n_D^{20} = 1,3330)

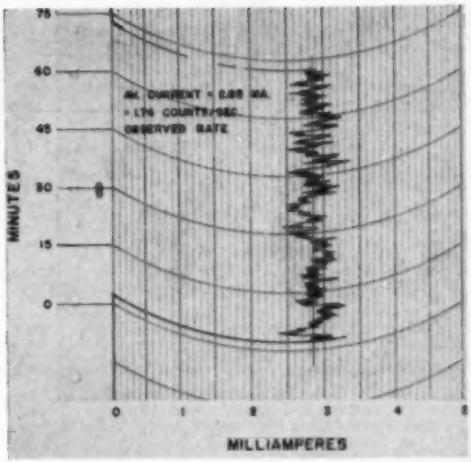


Fig. 8. Typical background record of continuous-flow sample counter with rate meter and recorder.

or calcium carbonate, and to count the dried, solid precipitate with a thin-window Geiger counter (*5*) or a windowless counter operating in the proportional region. These solid sample methods require a great deal of painstaking care in sample preparation, and are less sensitive than gaseous methods by a factor of 10 or more. Gaseous carbon dioxide has been assayed in ionization chambers (*10, 11*) and in Geiger counters (*2, 7*). These gaseous methods are quite sensitive, and therefore are especially suitable for work with low concentrations of radioactivity, but they usually require special glass vacuum systems, liquid air and/or dry ice traps. The ionization chamber techniques require delicate electric circuits and may need elaborate shielding to insure satisfactory stability.

Simpler assay methods would permit a greater utilization of radioactive carbon-14 in chemical and physical investigations. It is important to eliminate the oxidation of the carbon to carbon dioxide, since incomplete oxidation will introduce significant error. Also, the procedures required for oxidation take a great deal of time. For this reason, a considerable amount of effort has been devoted to the development of a method for the assay of volatile liquid samples which contain carbon-14 in the form of tagged methanol.

Because of the low energy (0.154 *Mev* max.) of the beta particles emitted by carbon-14, only a thin layer of the sample adjacent to the surface contributes to the count when solid or liquid samples are analyzed. The thickness of this layer is equal to the maximum range of the emitted beta particles in the sample material, and is about 0.2 to 0.4 mm. for liquids of densities from 1.5 to 0.7 g./ml. respectively. For samples having greater than "saturation" thickness, the measured rate of emission for a given specific activity will be directly proportional to the area of exposed surface. Therefore, for a maximum

TABLE 4.

VAPOR-LIQUID EQUILIBRIUM DATA OF METHANOL-WATER MIXTURES AT 760 mm. Hg

Temperature °C.	Mole Percent Methanol in Liquid	Vapor
64,65	99,6	99,7
66,62	87,5	94,0
68,32	77,1	91,2
70,65	62,1	83,7
73,13	50,5	77,4
74,26	44,0	74,7
75,64	38,6	71,9
77,47	32,5	67,6
79,36	25,9	61,1
80,94	22,0	55,4
82,37	18,6	50,8
83,55	15,8	46,2
86,34	13,5	43,0
86,22	11,7	40,3
87,11	8,0	30,0
91,69	5,6	20,3
94,85	3,2	12,5
96,42	2,3	10,4

Analysis by density measurements.

TABLE 5.

LIQUID-VAPOR EQUILIBRIUM DATA OF ETHANOL-WATER MIXTURES AT 760 mm. Hg

Temperature °C.	Mole Percent Ethanol in Liquid	Vapor
98,93	0,44	5,1
97,05	1,1	12,3
92,30	3,4	26,1
88,32	6,8	38,3
87,47	7,7	41,1
85,49	11,6	46,4
84,75	13,5	47,6
84,34	14,7	49,9
83,47	17,7	51,6
83,42	17,8	51,9
82,94	20,7	53,6
82,50	23,3	54,4
82,56	23,6	54,1
81,99	27,0	56,2
81,84	28,7	57,2
80,90	36,1	60,9
80,92	37,0	60,1
79,91	48,0	64,5
78,16	90,4	90,0

Analysis by density measurement.

TABLE 6.

VAPOR-LIQUID EQUILIBRIUM DATA OF n-HEPTANE-METHYLCYCLOHEXANE MIXTURES AT 760 mm. Hg

Temperature °C.	Mole Percent n-Heptane in Liquid	Vapor
101.0	0	0
100.7	6.6	7.8
99.8	23.0	23.9
99.5	40.7	42.7
99.5	57.7	59.8
99.1	70.0	71.9
98.9	80.0	81.0
98.4	100.0	100.0

Analyses by refractive index.

TABLE 7.

VAPOR-LIQUID EQUILIBRIUM DATA OF METHANOL-WATER MIXTURES AT 760 mm. Hg

COMPARISON OF ASSAY BY COUNTING WITH ASSAY BY DENSITY MEASUREMENTS

Temperature °C.	Mole Percent Methanol in Liquid		Vapor	
	By Count	By Density	By Count	By Density
65.6	0.918	0.940	0.963	0.970
67.6	0.813	0.831	0.918	0.934
76.7	0.349	0.368	0.703	0.696
78.7	0.290	0.281	0.643	0.657
82.1	0.225	0.206	0.593	0.583
82.9	0.182	0.180	0.552	0.552
83.9	0.150	0.160	0.516	0.525
85.1	0.154	0.160	0.490	0.490
88.1	0.0076	0.0989	0.390	0.413
89.9	0.0750	0.0783	0.352	0.370
91.5	0.0595	0.0644	0.308	0.320
92.5	0.0523	0.0550	0.294	0.300
94.0	0.0372	0.0470	0.222	0.234
95.3	0.0321	0.0321	0.190	0.195

response, the assay method should present the largest possible surface of sample to the detector. For maximum sensitivity, the ratio of this surface to the volume of the sample should be a maximum.

From a practical standpoint, the area of "active" surface (that surface to which the detector responds) is limited by the size of the sample which is available for the count, and also by considerations connected with the design of the detector.

If it is necessary to place a barrier or membrane between the sample and the sensitive portion of the detector, that barrier will likewise absorb part of the radiation from the sample and thus will reduce the response of the detector to the sample. Consequently, for good sensitivity, such membranes should be as thin as is consistent with the other requirements, such as mechanical strength and resistance to the passage of contaminating gases or vapors.

Because the energy of the beta rays emitted by the carbon-14 is so small, the slightest possible barrier should be interposed between the counter and the sample. Commercial thin-window Geiger counters proving unsatisfactory, two Geiger counters were designed and built in the laboratories. The first counter, termed the static counter, is shown in detail in Figures 1 and 2 and in the complete counting assembly in Figures 3 and 4. The liquid sample is introduced on the tray above the counter. The bottom of the tray is made of thin mica (1.7 to 2.5 mg./sq.cm.) which allows passage of the beta radiation from the sample into the counting atmosphere. A glass cap (not shown in the drawing) with a ground rim covers the tray in order to prevent evaporation losses. The joint between the cap and the tray is sealed with stopcock lubricant. The sample is injected on the tray from a hypodermic syringe, which is inserted in a small hole in the cap. The hole is then covered with a small square of tape. In spite of the thinness of

TABLE 8.

VAPOR-LIQUID EQUILIBRIUM DATA OF METHANOL-ETHANOL MIXTURES AT 760 mm. Hg BY TRACER TECHNIQUE

Temperature °C.	Mole Percent in Liquid			Vapor		
	Methanol	Ethanol	Water	Methanol	Ethanol	Water
73.92	27.53	71.43	1.04	37.74	61.36	0.90
71.8	37.45	61.16	1.39	50.94	48.33	0.73
71.1	40.08	58.28	1.64	60.45	38.62	0.93
70.1	55.10	42.76	2.14	67.14	31.73	1.13
75.8	15.66	83.06	1.28	23.61	75.37	1.02
72.9	32.61	65.95	1.44	42.89	56.01	1.10
72.06	38.45	59.83	1.72	51.65	47.34	1.01
70.9	49.08	48.95	1.97	63.60	34.87	1.53
69.8	59.45	38.47	2.08	68.83	29.81	1.36
68.9	64.79	33.01	2.18	74.96	23.89	1.15
68.1	69.61	28.17	2.22	79.71	18.99	1.30
67.7	76.67	21.13	2.20	82.99	15.78	1.23
67.1	78.29	19.96	1.75	85.43	13.69	0.88
66.8	78.07	20.20	1.73	88.20	10.96	0.84

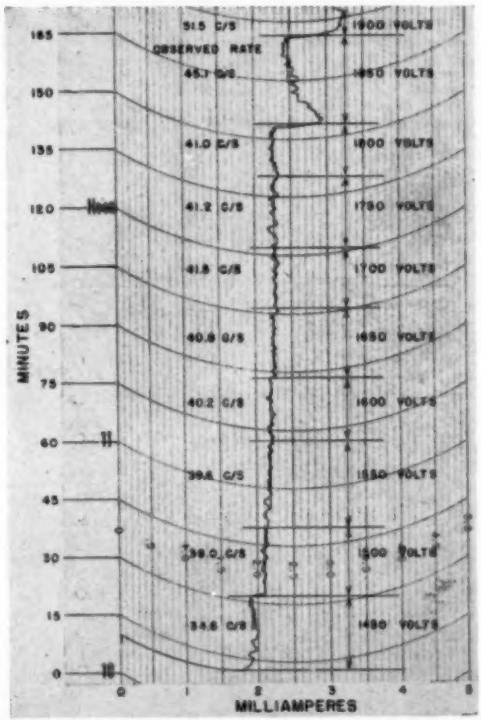


Fig. 9. Typical plateau record of continuous-flow sample counter with rate meter and recorder.

the liquid layer on the tray, no appreciable loss by evaporation occurs during a period of two or more hours. Consequently, samples of low activity may be counted for long enough periods to allow statistically satisfactory accuracy. After a count has been made, the tray is removed from the counter and is replaced by a clean, dry tray. The tube is then purged of air at a helium flow rate of 4 ml./sec. for a 10-min. period, when it is ready for another count. The used trays are cleaned by washing them with water and methanol, and exhibit no memory.

A series of daily counts made on a stock solution is shown in Table 1. A typical determination of the activity of a sample is given in Table 2. There are day-to-day variations in the counting characteristics of the tube. The operator determines these variations by counting a standard sample each day and by applying a tube correction factor to all the assay counts made on that day. Corrections are made also for background and coincidence losses. Background counts result from cosmic rays and other stray ionizing particles which find their way into the tube. The electrical circuits associated with the tube have a certain dead-time and if an impulse is received from the tube during that period the scalar will not tabulate. The loss in counts caused by this phenomenon is known as coincidence loss.

During the work with the static-sample counter, it became apparent that a counter capable of monitoring a liquid stream might be practicable. A continuous record of the activity, and from this the weight per cent of the tagged component, could be obtained by attaching to the counter a device which would continuously record the counting rate. A cross section of the continuous-flow counter is shown in Figures 5-7. Except for the details of the sample chamber containing the liquid and the provision for operation slightly above atmospheric pressure, the counter is identical with the static counter. The background of the counter is 1.8 to 2.5 counts/sec.—about the same as that of the static counter. A typical background trace appears in Figure 8. The random nature of the background is clearly apparent from the trace. Processes of radioactive decay also exhibit these random fluctuations, and they are observable on the traces. A typical plateau record of the tube is given in Figure 9. The plateau normally extends from 1500 to 1850 v. with a rise of 3%/100 v.

The choice between the static and the flow counter is determined primarily by the type of measurement desired. If a number of samples are to be analyzed, the static counter would probably be bettter. For the continuous recording of a stream the continuous-flow counter would be preferable.

Although both of these counters were developed for analyzing solutions containing carbon-14, they may be used in the analyses of other compounds which are sources of weak beta emitters such as sulfur-35 (0.169 Mev.), calcium-45 (0.25 Mev.), chlorine-36, (0.64 Mev.). Obviously they could also be used for stronger sources emitting either beta or gamma rays.

Vapor-Liquid Equilibrium Data

The accurate knowledge of the composition of a vapor that is in equilibrium

TABLE 9.

EXTRACTION EQUILIBRIUM DATA
METHANOL - n-BUTANOL - WATER
AT 30°C AND ONE ATMOSPHERE

Run No.	Weights Added - g.			Volumes - Ml.,		Densities - d_4^{30}		Wt.-% Methanol*	
	Methanol	Butanol	Water	Water Layer	Butanol Layer	Water Layer	Butanol Layer	Water Layer	Butanol Layer
1	1,027	17,366	19,930	17,45	23,05	0,9785	0,8430	3,16	2,40
2	1,699	16,964	20,220	17,80	23,22	0,9749	0,8473	5,01	3,87
3	2,627	18,178	19,911	16,39	28,97	0,9693	0,8525	7,40	5,76
4	3,162	17,254	19,486	15,15	29,10	0,9681	0,8581	8,66	7,43
5	3,918	16,875	20,065	15,11	30,08	0,9592	0,8657	10,42	9,47
6	4,700	17,745	24,822	20,88	31,10	0,9580	0,8664	10,98	9,78
7	5,481	17,929	25,252	19,25	34,40	0,9491	0,8767	11,63	11,10
8	4,240	9,125	22,483	29,71	10,30	0,9494	0,8753	12,10	11,10
9	4,637	13,213	22,503	22,20	20,55	0,9467	0,8790	12,20	11,45
10	1,694	12,187	18,296	18,61	16,30	0,9730	0,8490	9,77	4,61
11	4,771	11,995	21,134	21,98	17,72	0,9369	0,8929	13,60	13,24
12	5,434	11,515	21,821	26,30	17,60	0,9462	0,8821	12,39	11,46
13	5,193	14,762	22,149	13,37	32,90	0,9370	0,8932	13,24	13,01
14	0,916	22,807	1 9,098	16,40	31,68	0,9800	0,8424	2,52	1, 83
15	3,398	10,244	20,832	21,86	15,47	0,9610	0,8618	9,80	8,40
16	1,138	12,167	20,718	20,28	16,70	0,9782	0,8469	3,71	2,88
17	1,461	11,305	20,793	20,64	15,57	0,9763	0,8450	4,48	3,55

*Determined by Radioactivity Measurements.

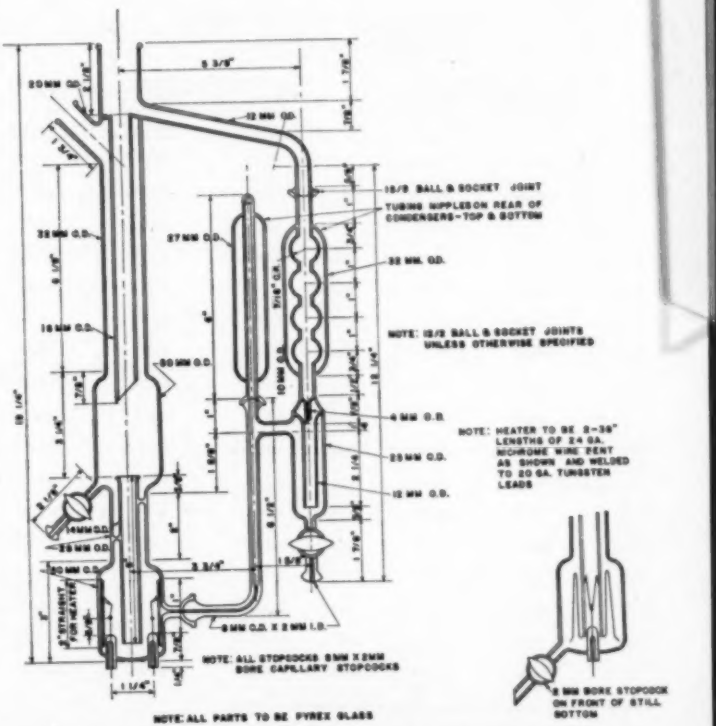

20 MM OD
12 MM OD
22 MM O.D.
16 MM O.D.
80 MM O.D.
87 MM O.D.
10 MM O.D.
18/9 BALL & SOCKET JOINT
TUBING NIPPLE ON REAR OF CONDENSERS - TOP & BOTTOM
22 MM. O.D.
NOTE: 18/9 BALL & SOCKET JOINTS UNLESS OTHERWISE SPECIFIED
4 MM O.D.
25 MM O.D.
12 MM O.D.
NOTE: HEATER TO BE 8-30" LENGTHS OF 24 GA. NICHROME WIRE BENT AS SHOWN AND WELDED TO 20 GA. TUNGSTEN LEADS
14MM O.D.
25 MM O.D.
20 MM O.D.
4 MM O.D. X 2 MM I.D.
NOTE: ALL STOPCOCKS 8MM X 2MM BORE CAPILLARY STOPCOCKS
8 MM BORE STOPCOCK ON FRONT OF STILL BOTTOM
NOTE: ALL PARTS TO BE PYREX GLASS

Fig. 10. Modified Othmer still for tracer study.

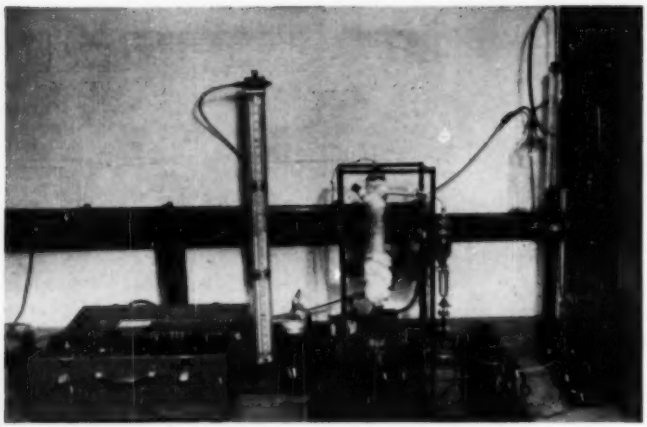


Fig. 11. Equilibrium still assembly.

with a liquid mixture, at a given temperature and pressure, must precede the design of a distillation plant. Use of a tagged component will permit a rapid determination of the amount of that component present in equilibrium samples and thus will simplify the problem of a complete analysis of the samples.

In order to evaluate the applicability of tracer methods to such a problem, it is desirable that the samples tested truly represent equilibrium conditions; then any observed deviations from known values may be attributed to the assay method alone.

The problem of obtaining equilibrium data has been discussed by Othmer (*14*), and various methods have been developed which have achieved more or less success (*8,12,15,16*). The considerable effort still being devoted to the problem (*6,17*), indicates that a wholly satisfactory solution has not yet been achieved. The apparatus and methods described in the following pages have given results which compare well with those of other investigators, and have certain advantages where trouble-free operation is of great importance. Figure 10 shows in detail the equilibrium still used. Figure 11 is a photograph of the equipment assembly.

Three systems were employed in checking the performance of the still, methanol-water, ethanol-water, and methylcyclohexane-*n*-heptane. The properties of the materials used are tabulated in Table 3. Results are shown in Figures 12-14, and are tabulated in Tables 4-6. From these results it was concluded that the equipment was satisfactory.

TABLE 10.

MATERIAL BALANCES -- EXTRACTION
EQUILIBRIA OF METHANOL - n-BUTANOL - WATER
AT 30°C AND ONE ATMOSPHERE

	Overall Balance			Methanol Balance		
Run No.	Total Weight Added Grams	Total Weight Observed Grams*	Difference Percent	Weight CH_3OH Added Grams	Weight CH_3OH Observed** Grams	Difference Percent
1	38.32	38.19	-0.35	1.027	1.046	+1.86
2	38.88	38.72	-0.42	1.699	1.696	-0.19
3	40.72	40.58	-0.33	2.627	2.593	-1.30
4	39.84	39.59	-0.63	3.162	3.121	-1.28
5	40.86	40.53	-0.80	3.918	3.975	+1.46
6	47.27	46.95	-0.68	4.700	4.244	-9.70
7	48.66	48.43	-0.49	5.481	5.471	-0.19
8	35.85	37.22	+3.83	4.240	4.413	+5.97
9	40.35	39.08	-3.16	4.637	4.632	-0.12
10	32.18	31.95	-0.71	1.694	1.683	-0.67
11	36.91	36.04	-2.65	4.771	4.844	+1.54
12	38.77	40.41	+4.23	5.434	4.862	-10.52
13	42.10	41.91	-0.45	5.193	5.200	+0.12
14	42.82	42.76	-0.14	0.916	0.880	-3.88
15	34.47	34.36	-0.34	3.398	3.117	-8.27
16	34.02	33.90	-0.36	1.138	1.140	+0.16
17	33.56	33.31	-0.75	1.461	1.369	-6.29

* From density and volume measurements of the two phases.

** From activity measurements, densities, and volumes of the two phases.

Methanol-Water Equilibrium Data (Tracer Technique). Vapor-liquid equilibrium data were obtained on the methanol-water system using radioactive methanol as the tracer. The results of these determinations are given in Table 7 and Figure 15. Results indicate that the amount of methanol in methanol-water mixtures can be determined with an average error of about 1.0 mole %, using the tracer method. The results of several additional determinations made in the region of low methanol concentration, with tagged methanol having a specific activity approximately four times that used in the other runs, are plotted in the lower left-hand corner of Figure 15; they agree with the other data.

Methanol-Ethanol Equilibrium Data (Tracer Technique). Methanol-ethanol mixtures are difficult to analyze by conventional methods employing the measurement of densities or refractive indexes. The densities of methanol and ethanol, and of mixtures of these alcohols, are all nearly the same, and the refractive indexes do not differ sufficiently to afford accurate analysis. Radioactive tracers will simplify the analysis.

Vapor-liquid equilibria for the methanol-ethanol system appear to have been determined previously by only one investigator. The published data of Hausbrand (*9*) show that the mixture deviates significantly from ideal behavior particularly at the extremes of the composition range. In view of the close chemical similarity of the two components, it would be expected that the mixture would be nearly ideal. Because of the lack of confirmatory determinations of the system, the experimental data are often ignored, and ideal behavior is assumed in calculations of the equilibrium relationships.

Radioactive tracer methods for sample analysis were used in a number of equilibrium determinations on the system. The techniques were the same as those used in the study of methanol-water equilibria by tracer methods. The modified Othmer still was used, and samples were analyzed by radioactivity

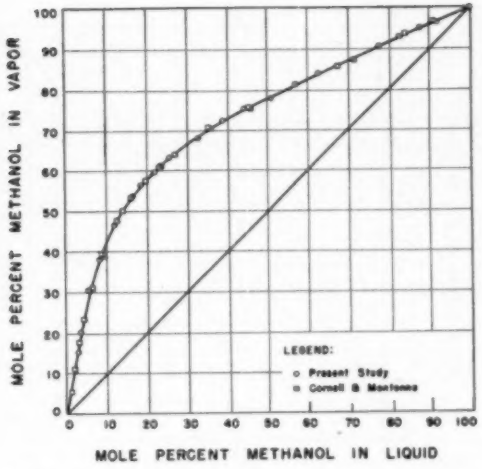


Fig. 12. Performance check on modified Othmer still methanol-water equilibria at 760 mm. Hg.

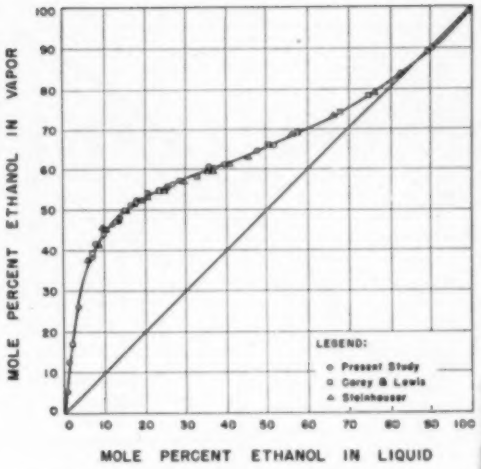


Fig. 13. Performance check on modified Othmer still ethanol-water equilibria at 760 mm. Hg.

measurements, as described previously. Experimental results are given in Table 8 and are compared with the previous experimental work and with the values predicted from Raoult's law, on Figure 16. Unfortunately, small traces of water were present in the radioactive methanol used and the results show only the application of the tracer method and not its accuracy. More data are being obtained on this system with water-free methanol.

Other Applications. As additional compounds are synthesized the vapor-liquid equilibrium data of multicomponent systems can be determined by changing from one radioactive tagged molecule to another in the system. By placing the flow counter in the tube conveying the vapor condensate, a continuous analysis of the vapor can be made and thus the establishment of steady-state conditions observed. The quantity of radioactive tracer can be adjusted so that dilute solutions can be analyzed with relatively high accuracy.

Extraction Equilibria by Tracer Methods

During the course of the work on the analysis of vapor-liquid equilibria by means of tracers, it became evident that the same methods of analysis could be applied with advantage to other types of physical studies of interest in chemical engineering work, such as the determination of component distribution in two-phase liquid systems at equilibrium. Such information is necessary to the design of liquid-liquid extraction equipment, like that used in the petroleum and chemical industries.

To demonstrate the applicability of these methods, a brief study of the system methanol-*n*-butanol-water was made.

Methanol having a small proportion of radioactive carbon atoms was used as the tagged component. The *n*-butanol used was

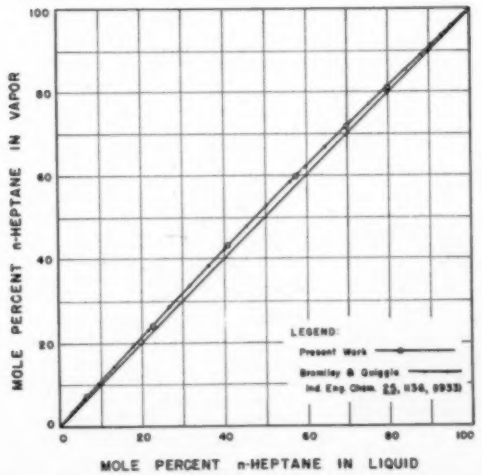


Fig. 14. Liquid-vapor equilibria for *n*-heptane-methylcyclohexane at 760 mm. Hg.

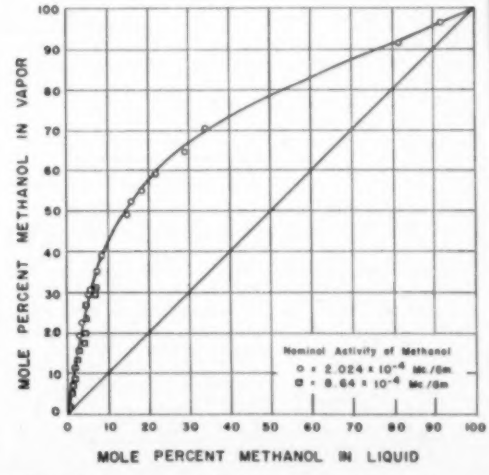

MOLE PERCENT METHANOL IN VAPOR
MOLE PERCENT METHANOL IN LIQUID
Nominal Activity of Methanol
○ = 2.024 x 10⁻⁴ Mc./Gm.
□ = 8.64 x 10⁻⁴ Mc./Gm.

Fig. 15. Liquid-vapor equilibria by tracer methods methanol-water system at 760 mm. Hg.

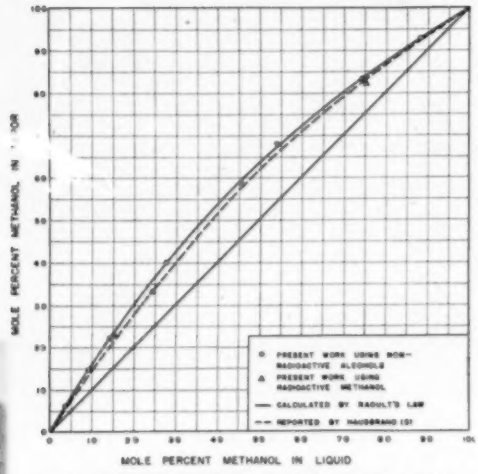

MOLE PERCENT METHANOL IN VAPOR
MOLE PERCENT METHANOL IN LIQUID
PRESENT WORK USING NON-RADIOACTIVE ALCOHOLS
PRESENT WORK USING RADIOACTIVE METHANOL
CALCULATED BY RAOULT'S LAW
REPORTED BY HAUSBRAND (2)

Fig. 16. Liquid-vapor equilibria by radioactive tracer methods methanol-ethanol system at 760 mm. Hg.

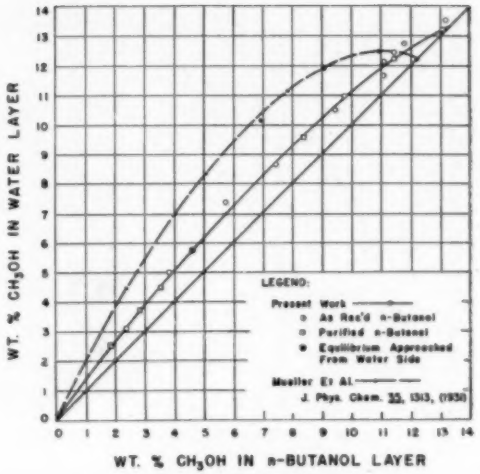


Fig. 18. Methanol-n-butanol-water. Methanol distribution at 30° C. and one atmosphere.

Mallinkrodt Analytical Reagent Grade. Most of the runs were made with the material as received. No significant differences were observed, however, with a center-cut from a distillation. Complete solubility data and component-distribution data were obtained, at 30° C. and one atmosphere, for the liquid-phase region of this ternary system. The component-distribution results show marked disagreement with the earlier work of Mueller, Pugsley, and Ferguson (*13*), who used less direct methods for determining the distribution of methanol between the water-rich and n-butanol-rich phases. Material balances, both overall and on the methanol portion, were calculated for the present results, and lend credibility to the data obtained by tracer techniques. The ternary diagram is shown in Figure 17. The weight per cent methanol in the water and butanol layers is found in Figure 18.

The equilibrium data on the system is presented in Table 9 and the material balances in Table 10.

Conclusion

Tracer compounds were successfully used as substitute and auxiliary analytical agents in the determination of vapor-liquid and liquid-liquid equilibrium data.

Acknowledgment

This program was supported initially by the Office of Naval Research, and is now being sponsored by the Atomic Energy Commission.

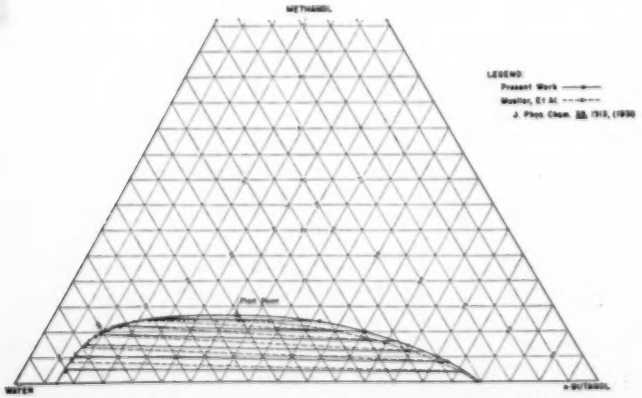


Fig. 17. Ternary solubility diagram methanol-n-butanol-water at 30° C. and one atmosphere.

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(Presented at A.I.Ch.E. Kansas City (Mo.) Meeting.)

INDUSTRY AND COLLEGE CAN COOPERATE!

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"The St. Louis Plan" would probably identify this article more accurately for our readers. . . . Here is the genesis of a co-operative movement between industry and education . . . a plan which yields help to both . . . a plan which uses the best talents and skills of engineers in industry . . . and sharpens them through use. . . . Here is a bold, unselfish plan for emulation . . . plus many other sincere suggestions taken from a survey on how educators and industrialists can help.

ENGINEERS in industry are quick to criticize our educational system, but slow about doing anything to help. To be fair, it must be said that pedagogues are often overly critical and demanding of industry and do little or nothing to help eliminate the conditions they deplore.

The truth seems to be that both schools and industry are doing a big job and are doing it well, and that there are many ways they can work together for mutual improvement. In our highly industrialized economy, with its ever-growing demands for trained and educated people, better cooperation between the organizations that train and educate, and those that employ would be highly desirable. Furthermore, those involved are highly intelligent and therefore ought to be able to pool their efforts effectively, provided there is leadership at a high level.

Survey

There are a few "hardy perennial" suggestions for cooperative effort through which colleges and industry might improve chemical engineering education. In an effort to get beyond these rather elementary and sometimes unrealistic ideas, a note was sent to each of the ninety-four A.I.Ch.E. Student Chapter counselors asking each man to quiz his colleagues and to answer the question, "How can industry and colleges cooperate better to improve chemical engineering education?" Replies were received from well over half of those polled and these letters set forth 272 proposals. After scrutiny these were classified into 82 separate ideas.

Meanwhile, men in industry were asked the same question and their responses, though not treated so formally, gave rise to a number of interesting proposals, some of which duplicated those advanced by the educators. Taken together, the evidence shows that there are innumerable ways to improve cooperation between industry and the technical schools, and that opportunities exist which we are, as yet, doing very little to grasp. It seems certain that enormous strides can be taken by starting to do now some of the things suggested without waiting and without argument over the obstacles that may be encountered. There is described later in this paper, the St. Louis Plan, through which the St. Louis Section of the American Institute of Chemical Engineers and the Chemical Engineering Department at Washington University are cooperating in an effort to improve chemical engineering education, and the effort is without a doubt a demonstrated success.

Survey Results

A statistical analysis of the suggestions otained from men in industry and education is of little moment but it is interesting to note the three proposals which occurred most often:

Industry should arrange summer employment for teachers.

Industry should finance more graduate fellowships.

Industry should give summer employment to students.

Another group of three had many proponents:

Industry should employ teachers for a year or more at a time, and schools should give leaves of absence for this purpose.

Industry should employ more teachers as consultants.

Industry should supply speakers for student gatherings, such as student chapter meetings.

The education of chemical engineers takes place initially on the campus, but education can be effected in many ways. Most of the ideas for improving chemical engineering education are ideas for industry to work on, and for actions affecting campus affairs or conditions.

W. T. Nichols is director of the general engineering department, Monsanto Chemical Co., since 1949, and 1952 Vice-President of A.I.Ch.E. Prior to this association with Monsanto he had been technical assistant to the executive vice-president of Westvaco Chemical Division of the Food Machinery and Chemical Corp., New York. A graduate of the University of Pittsburgh, he joined the research staff of Mellon Institute, and subsequently was appointed research engineer for Columbian Rope Co., Auburn, N. Y. In 1930 he joined Westvaco, and in 1935 was made director of research and development. Readers will remember him for his many guest editorials and for his article, "Illusions of Success," a philosophical approach to the profession of engineering and published in "C.E.P." in March, 1947.

One man expresses himself thus:

> Let industrialists support word with action who say it is to the best interests of industry to spend thought and money on improving the quality of instruction and the caliber of the technical graduate.

Another feels somewhat differently. He says:

> I am interested in developing cooperation between industry and the technical schools in all of the many ways possible. Certain of them can be accomplished by industry with the certainty that they will be appreciated by the schools. There are a number of other types of cooperation which industry is not in a position to initiate and which require an invitation from the school: The important thing to emphasize, I think, is that the *educators should devote much more energy and resourcefulness to developing these relationships.*

One man believes that industry should do more to alert its engineers and scientists to the need of cooperating, as individuals, with the colleges and universities on the subject of conferences, symposia, and joint meetings, particularly where the two groups are proximate. Another feels that schools should take the lead in organizing seminars with both academic and industrial speakers to study problems of industry and education. One man makes the point that industry ought to do more publishing than it does even though this means taking time from pressing work to prepare publications. Another feels that more articles should be encouraged from industry sources, of a comparatively non-technical nature, which would be gauged to appeal to the student, particularly on subjects such as vocational guidance.

Some feel that measures should be taken to encourage more contacts between teachers and industrialists as, for example, by making it possible for professors and junior staff members to attend more professional society meetings, and others say that teachers need to come down out of their ivory towers.

Financial Aid to Schools

Financial aid to schools by industry is a popular topic among industrialists as well as among educators. Tax laws have virtually eliminated big gifts by individuals, and financial burdens are nearly insupportable at many centers of education especially at some of the smaller schools, many of which do excellent work. At the same time, intelligent educators seem to fear government control as a result of government financial support.

The proposal which ran second in the school survey had to do with industry fellowships for graduate students. This seems to be a great need and there has been a lot of activity in this field for some time. The same proposal turns up in other forms, such as suggestions for cooperative research, through which industrial projects are contracted to universities; suggestions by industry for research problems that have application in industrial work and which could be financially supported by industry; financial support by industry for university research projects which do not have immediate pay-off attraction; and so forth. One man called attention to the advisability of adding to the usual grant several hundred dollars per fellowship to help the department finance needed equipment and instruments. The smaller schools appear to need more consideration than they are getting.

Teachers say, rather bitterly, that industry should not hire away good teachers but rather should subsidize them to teach. There is considerable educator sentiment in favor of direct contributions by industry to defray operating expenses of technical school departments, and many believe that such gifts wou'd be far more valuable to the school than restricted grants for scholarships and fellowships. Several people hope for the endowment, by industry, of professional chairs or laboratories in the more progressive, smaller technical schools which otherwise could not afford these measures.

Many contend that industry should make used equipment available to chemical engineering schools, or at least somehow help them to obtain useful pilot plant equipment.

Non-Financial Aid to Schools

Though financial aid is of great importance, there appear to be ways for industry to work with colleges which do not involve direct subsidy of students, teachers, or schools. Many suggestions are made which point up the value of educational material, such as flow sheets, samples, exhibits, films and so forth, which industry can supply. A number hold that industry might well supply literature describing the work of the chemical engineer, suitable for high school seniors and college freshmen. But one professor insists that instructors do not try hard enough to round up and make use of such technical movies and material as are already available from industrial concerns.

It has been proposed that some industrial organization should sponsor and control the development of modern audio-visual teaching aids, and industry review of technical textbooks.

Several people made the point that industry should make technical information available to instructors and advanced students when this will not endanger company secrets. Industry might also suggest topics for literature surveys in thesis courses.

One interesting suggestion is that typical industrial "case studies," which follow a problem from inception to completion, including false starts and errors, would be of value to teachers and could be prepared by cooperative effort between teachers and men in industry.

Perhaps the most radical suggestion for non-financial aid to schools, was that industrial concerns maintain pilot plant laboratories for the use of near-by universities, presumably because the industrial plant has services and facilities beyond the reach of the ordinary school. One such arrangement is said to be in effect.

There is an opportunity for industry to serve schools by supplying useful material aids to teaching, and it seems likely that this can often benefit the company supplying the aid. Futhermore, it would seem reasonable to employ educators in working up plans for these activities.

Industrial People on the Campus

There are myriad ways in which industries' chemical engineers can be of beneficial use on the campus. It seems easier to get suggestions of this sort than any other, but judging from reported experiences of both teachers and industrialists, implementation does not appear to be so easy. The simpler suggestions are for industry to supply lecturers, guest instructors, teachers for evening sessions at the professional level, and speakers for student chapter meetings. Some recommend that arrangements be made for chemical engineers from industry to spend at least a few years in teaching, or, set up a system of rotating lecturers alternating between school and industry. Others contend industry should subsidize some of its men on a loan basis to schools as specialists to conduct graduate courses and to work with the faculty. The intent seems to be that chemical engineers in industry achieve viewpoints and experience which are beneficial to education.

Suggestions are made for frequent student seminars to be addressed by industrial people, or symposia about developments such as powder metallurgy, sulfuric acid manufacture, or polystyrene.

A novel plan at one university uses young but experienced engineers from industry to help chemical engineering seniors with design problems. An afternoon every two or three weeks is thus spent. At some schools industrialists are used on advisory committees to aid

engineering faculties, though one man recommends strongly against this measure as being of no real use. Schools might have an occasional open house so that industry can see what the school is doing, and perhaps participate in the study of problems.

Teachers in Industry

There are any number of ways to bring about useful contacts for teachers in the industrial environment. In general, sentiment seems to be strong among educators and industrialists, alike, that teachers need to rub elbows with industry and there is a strong feeling that industry ought to finance this activity in some way. Companies also might hold an open house or a conference for teachers, to work out ways to get together to mutual advantage. Some even suggest that teachers and industrialists trade jobs for a year or so. One man believes that the A.I. Ch.E. Committee on Chemical Engineering Education ought to head up and coordinate a program under which perhaps twenty companies would employ one or more teachers for a year or two and pay them well. It has been proposed that industry organize training courses for teachers during the summer months with the teachers shifted from one department to another so as to see how the company functions. *The proposal which outran all others in number and vehemence is that summer jobs for teachers ought to be arranged by industry as a direct aid, and the belief is widespread that the benefits would extend far beyond the important financial aspect.* One teacher suggests that someone establish a placement service bureau which would invite faculty members to apply for short periods of industrial employment. A popular proposal is that teachers be given a year in industry, from time to time, as is now being done in a few of the larger chemical companies.

Sentiment is strong among the professors in favor of more employment of teachers as consultants. It is even suggested that industry could help by employing teachers as consultants and then not consuming any appreciable part of their time. Some feel that industry could farm out design problems to be worked on by faculty men at their own locations.

One interesting proposal was that teachers could be employed by industry to do spot educational jobs of a short-range type helpful to sales engineers, plant operators, and so forth. Similarly it was suggested that teachers give organized instruction to industrial people at their place of work.

The use of teachers in industry is an area of cooperation where there is an opportunity to accomplish a great deal, particularly when technical manpower is short. For best results, industry will have to *want* to employ teachers and be willing to work hard to learn how to do so. On the other hand, teachers should not expect to get something for nothing. Certainly more opportunities for chemical engineering teachers to observe the workings of industry, and to participate actively, ought to be beneficial.

Direct Aid to Students

Year by year, education beyond the high school level becomes more common. There are those who believe that the time is not far off when communities will establish higher education on a free basis. Many communities already have a two-year college curriculum in their local Junior Colleges. A large number of young people seem to be able to reach the college campus with little or no effort on their part and many others manage to eke out a degree by either partial or total self-support. A large number of scholarships are granted by the schools, but financial burdens tend to hold back the growth of this scheme.

In spite of the great advance in the economic level of our people, and all the things that have been done to aid students, more can be done.

The belief is widespread among teachers that students ought to be employed for summer work in industry. A few recommend an increase in the co-op system under which students alternate between industrial employment and school. It is felt by several that an employment clearinghouse for student summer employment would be useful. There are a few suggestions having to do with provision by industry of funds for prizes for worthy student activities, such as for papers presented by students at regional conferences of chemical engineering seniors. Aside from summer employment, however, the most serious proposals for direct aid for students have to do with scholarship support. Both teachers and industrialists seem to believe that to increase interest in the engineering profession industry might well provide far more scholarships. Competitive examinations, or scholastic record and need, are indicated as criteria. One man proposes that industry hire men at the B.S. level subject to a further year of graduate study, supplying the scholarship for the added year. One rugged individualist, a teacher, holds that direct financial aid to students by industry is not a matter of first line importance, for he feels that the best young people will somehow arrange to get advanced education without much aid from anyone else.

The demand for summer employment for students is so strong and so broad that a real opportunity exists for great accomplishment right away. It is probable that there is far less security risk involved than is commonly claimed. Here again, leadership is needed, and here again is an opportunity for the teachers to take the initiative and for chemical engineers in industry to take an open-minded look at this chance to help and, incidentally, to get a line on good men shortly to become available.

Inspection Trips for Students

It is evident that many teachers place great importance on plant visits by students. Some feel that plants do a fine job with inspection trips and others feel that they do a perfectly miserable job. The evidence is that industry ought to make inspection trips by students the occasion to give industrial knowledge and education to the students rather than letting these inspections degenerate into mere sight-seeing trips. A number of industrialists and teachers feel that the ideal inspection trip would call for a rather rapid tour, to show off the general aspects of a plant layout; a detailed discussion of some one or two areas, selected so this might be done without prejudice to the company's security; carefully selected guides who are adequately briefed and who talk under conditions that everyone can hear well and easily; and, above all, an opportunity, however brief, for the students to rub elbows with men who are well up the scale of accomplishment in chemical engineering.

I am certain that chemical companies would do well to review their policies on student inspection trips. The first question is whether to permit them grudgingly or to cooperate enthusiastically. If inspection trips are to be handled at all, then surely enlightened self-interest should dictate that both students and teachers get as much benefit as possible and above all, a fair and favorable impression of the organization under scrutiny. This is unlikely to occur if an inspection is regarded by plant management and employees either as a mere picnic occasion or as an eternal nuisance. Since teachers are usually in the position of beggars with regard to these trips, they seldom adopt a sufficiently energetic attitude toward setting up the kind of inspection trip that will do the most good. In general, they are willing to accept most gratefully any kind of offer they can get. It would seem far better for them to work politely but firmly toward good inspection trips and by-pass those plants and companies that are unwilling to cooperate all the way. Actually, a properly organized

inspection trip will cause less disruption and take far less effort on the part of everyone, than the kind of trips that usually take place. It is recommended that chemical engineering teachers give thought to *their* responsibilities in this matter and somehow organize a program to enlighten industry on the subject of the objectives and requirements of student inspection trips. Many engineers in industry will be glad to help and advise in any such effort.

Hiring of Technical Graduates

Some years ago, the American Society for Engineering Education worked up a proposed code of behavior applying to campus recruiting of engineers. Observance of this code would be a real contribution to better cooperation of industry and the colleges. There are still a lot of problems relating to hiring of chemical engineering graduates which need attention. Some of these have to do with the recruiting procedure and others go deeper. For example, when recruiting, industry might have a competent technical man accompany a personnel representative and, in a meeting with students the day before interviews, answer properly questions which the personnel man might not be able to handle. Others propose that, in any event, employment interviews would be greatly improved by holding a group meeting of all interested persons prior to the individual interview sessions so as to be able to explain the general aspects of employment and fringe benefits, once and for all, and thus be able to concentrate the individual interview on individual matters. It was suggested that a company should not limit employment interviews only to students above a certain grade point since many worthwhile men are overlooked if this is done.

A rather novel suggestion is that companies might well issue periodic reports to schools regarding trends and possibilities for employment, required qualifications, salary data, and so forth, and thus prepare the faculty in advance for the campus visit to take place later.

One man believes strongly that industry should re-examine its needs and separate its requirements into two groups, technicians and professional engineers. This person seems to feel that this would greatly improve the ability of the schools to train the kind of people that industry wants.

One teacher feels that ways should be found to show the management of smaller companies how they can benefit from employment of technical men. Another wants to do something to make employers understand better the functions and abilities of technical men and help the employers use technical men where the best results can be obtained from their training.

Sentiment is growing that industry should work to initiate a stable employment program for June graduates. Attention is called to the great evil of the cyclic large demand, and then lack of demand, for young graduates. Many people believe the periodic over-supply and under-supply of trained men can be laid at the door of the major employers. The feast or famine employment program certainly seems shortsighted and uneconomic. At least one man contends that this is the really big problem in improving relations between industry and the schools and that a real solution would be more constructive than any kind of direct or indirect support of students or teachers. It is only fair to point out that industry's problem has been greatly complicated by the conditions which have existed for the past fifteen to twenty years.

Instruction for Teachers

A perennial complaint among both teachers and engineers in industry is that teachers are too remote from chemical engineering practice and lack opportunity to keep up with their art. There are some quite definite proposals the intent of which is rather formal instruction of the teachers. It has been suggested that courses of instruction for teachers should somehow be established to acquaint them with problems in industry and specialized design methods. It is also suggested that more industry-sponsored sessions be organized for instructing engineering teachers in specific subjects. The type of sponsored sessions mentioned is that represented by the meetings organized by the A.I.Ch.E. Chemical Engineering Education Projects Committee in Houston in 1950, one of which had to do with sulfuric acid manufacture and the other with the design of heat exchangers. (*1*)

While this subject is not being ignored entirely, it is apparent that much more could be done. Impressive possibilities lie in merely bringing groups of teachers together at chemical plants or engineering departments. Such a foregathering of teachers and practicing engineers can do a lot of good, even though no significant program is arranged. These occasions are rather simple to arrange where industry is close to chemical engineering schools. Where this is not so, financial aid by industry toward travel expense might be helpful.

Integration of Teaching and Practice

One of the easiest arguments to start in chemical engineering circles is the four- or five-year curriculum for the bachelor's degree, and whether there shall be more or less "humanities" in the instruction. There are all shades of opinion as to whether education or training shall predominate. Industrial people, who employ the great majority of engineering graduates, are outspoken among themselves about curricular shortcomings, but seldom are vocable where it might do some good; for example, before pedagogues and college adminisrators. Teachers are sometimes rather haughty when industrialists try to express their vaguely perceived criticisms of the preparation young chemical engineering graduates have been given. This behavior is simply a reflection of the lack of understanding of the other's work and problems. There is no occasion for men in either field to look down their noses at those in the other field. Actually, almost all men in both fields are willing and anxious to help the others, if only someone will lead the way. Leadership is the great need.

The belief is widespread that industry and schools need to work toward better integration of teaching and practice. Some men feel that industry would do well to stop demanding graduates at the bachelor's level with specialized training pointed toward a particular industry rather than sound basic training. Some say that industry should explain to faculties and students how the various functions of a chemical engineering program are executed, either by furnishing lecturers or by supplying texts, or both. Some feel that formal engineering instruction should include an explanation of the nature of industrial enterprise and the problems and methods of operation involved. A few feel that there should be more of the sort of active industry participation in the student education program, which is exemplified by M.I.T. Practice School, and the like.

One suggestion was that industry as a means of informing faculties on the caliber of their instruction and the merit of their curriculum, might report to the schools, on a short, tabular, standard form, the progress of young graduates each year for the first three years.

There can be no question that a deep and abiding interest on the part of both teachers and practicing engineers in pooling their best ideas and translating them into action would greatly strengthen our system for chemical engineering education. The problem here is to develop means for commuication, contact and cooperation, and really do something rather than merely talking about it. Reference is made again to the St. Louis Plan which shows clearly one way by which schools, industry and professional society can do something

very real and of lasting benefit to all concerned.

Direct Aid to Industrial Employees

Many proposals for improving cooperation between industry and colleges take the form of direct aid of some kind to students or teachers or schools. There are some, however, which deal with aiding chemical engineers in industry. A popular proposal is for broadening of the program under which some of the larger companies give a year of academic leave to some of their employees. The sentiment is strong that companies might well do more to encourage their chemical engineers to pursue graduate studies or otherwise continue their education. Encouragement might take the form of giving time off or paying tuition for attendance for either day or night periods, as circumstances warrant. One man believes that schools should organize extension courses at the graduate level, and allow full residence credit, provided library facilities available to the industrial employee meet certain standards.

As may be seen, even these proposals have a substantial element of aid to, or support of, the educational institution. These proposals deal with measures which would bring about interesting contacts between teachers and students on the one hand and engineers from industry on the other.

The St. Louis Plan

The St. Louis Plan is pleasant to write about, not because the author had something to do with it but because it is a fine enterprise and a concrete example of *how* industry and colleges can cooperate to improve chemical engineering education. It furnishes a first-class example of the way to go about accomplishing something useful in the face of theoretical obstacles. The St. Louis Plan was described to the American Society for Engineering Education in June, 1951, by Dr. L. E. Stout, Dean of Engineering at Washington University, St. Louis. (*2*)

The St. Louis Plan developed from an informal conversation in 1949. Dean Stout remarked to the author that he was not very happy about one of his senior chemical engineering courses called "Plant Design" because, generally speaking, qualified teachers of engineering fundamentals are not particularly well equipped to give up-to-date, down-to-earth instruction in the matters commonly encountered by graduate engineers in industry. Dean Stout perceived the need to explain to his seniors just what chemical engineers may be expected to do in practice and was groping for better ways to do this. The author in turn mentioned certain lectures being given to chemical engineers in Monsanto's General Engineering Department to assist in professional development, as examples of the kind of instruction that young men need. As a consequence, one particular lecture was requested to be given to the senior chemical engineers at Washington University and it was received with such enthusiastic approval by both students and faculty that three more were arranged immediately.

The response indicated that a development of first-line importance was in the making. Speculations about substituting lecturers from industry for *all* of the lectures in the senior design course indicated forbidding obstacles, but it was decided to make the attempt, stipulating that any time the lecturer could not fulfill his commitment, a faculty man would take over.

A comprehensive series of lectures was outlined. Since the beginning of the second semester was imminent, it was necessary immediately to line up "volunteers" for the first few lectures. This gained time for planning, and other competent men were soon found to take on the rest.

What seemed like a huge job at the start turned out to be no trouble at all.

TABLE 1

Origin and Course of Development of an Industrial Project	
Concept of a Sound Industrial Project	
Discussion Session	
Cost and Property Accounting in the Chemical Industry	
Engineering Approach to the Cost Sheet	
Influence of Capital on Economic Design	
Influence of Insurance Requirements on Design	
Influence of Health and Safety Requirements on Design	
Corrosion Technology	
Materials of Construction of Chemical Engineering	
Fabrication of Chemical Equipment	
Materials Handling—Solids	
Materials Handling—Gas and Liquid	
Process Piping Design	
Electrical Design for Chemical Plants	
Structural Design for Chemical Plants	
Architectural Design for Chemical Plants	
Unit Operations and Material Balance	Design Tool Series
Development of Flow Sheets	Design Tool Series
Specific Equipment Design	Design Tool Series
Evaluation of Alternatives	Design Tool Series
Data for Design	Design Tool Series
Summation	Design Tool Series
Batch vs. Continuous Processes	
Fractional Separation	
Fractional Separation	
Fractional Separation	
Unfired Pressure Vessel Design	
Unfired Pressure Vessel Design	
Rotary Dryer, Calciner and Kiln Design	
Industrial Waste Disposal	
What Do You Want to Know About Your Job?	

The lectures were given from 9:00 to 10:00 A.M. on Monday, Wednesday, and Friday, and the arrangements and obligations were the same as for any other class. Periodic examinations were given by faculty members.

In all, there were thirty-two hours in the first series. The subjects are shown in Table 1.

Because of the conditions under which this series was planned, it was convenient to use members of the Monsanto General Engineering staff for most assignments. All other lecturers, except one, were from other departments of Monsanto. These lectures required relatively little preparation because each man was discussing subjects which he knew well and which constituted his daily task. Consequently, almost all that was involved was the time required to go to and from the University, the time to give the lecture, and then the time to pry loose from the interested class. This series turned out extraordinarily well, and students and teachers alike were enthusiastic and appreciative. The effect on the students and their attitude toward industrial work was prompt and striking. An extremely interesting and significant phenomenon was that the lecturers, to a man, were enthusiastic and felt rewarded for their effort.

At the end of this first series, no one involved had any thought other than that the same sort of series would be arranged for the following year, but with more time and a better chance to get ready. Exposure to the senior class gave lecturers an opportunity to size up potential chemical engineers. In spite of this great advantage, it would be in the long run unhealthy for this opportunity to be confined to one company. Consequently, when fall came, the author proposed to the Executive Committee of the St. Louis Section of A.I.Ch.E. that it sponsor the course in the future. The members of the Section agreed to take on the responsibility and as a result, not thirty-two but forty-two lectures were given by people, from not just one company, but from eleven companies. This course, taken for credit, was again enthusiastically received and there is no doubt in the minds of those involved, that the St. Louis Plan is an extremely important and significant method of industry-college cooperation; one which could have very broad and profound effects on technical training and education in general.

Under the St. Louis Plan, an A.I.Ch.E. section is able to supply specialized instruction at a highly expert level at no cost to the school and only a rather insignificant cost in terms of money, time, and effort to the lecturers or their employers. These men are simply talking about things they know well. No one

has to do very much, yet the sum total of forty-two lectures is tremendous! *The thing that sets the St. Louis Plan apart from anything even remotely related, so far as is known, is the number and regularity of the lectures, the integration and coverage of the subject matter and the fact that the course is given for credit. This must not be confused with having an occasional lecturer from industry.*

Only in certain circumstances is the plan not feasible. Before the first series was completed, Professor Luebbers of the University of Missouri, began to ask for something similar for his seniors. The University of Missouri is about 125 miles from St. Louis and lectures three times a week from 9:00 to 10:00 A.M. would not be feasible. There seemed a possibility that a team of three lecturers could work once each week. The St. Louis Section sent a number of these teams during the second semester of the past academic year. It appears that this plan has good possibilities, and there seems no difficulty in locating competent people who are willing to make this trip, or of employers willing to give the time and the expenses for such a purpose.

The St. Louis Plan is feasible at a great many locations and for all sorts of curricula,—not just chemical engineering. An attempt to interest other A.I.Ch.E. Sections in sponsoring similar plans in their own localities seems in order.

The St. Louis Plan was started with almost no preparation. Stopping to think up all the obstacles would have prevented ever getting started. Just a week after the thirty-second and last lecture of the first series, the author encountered a professor of chemical engineering and before parting told him about the adventure at Washington University. He must not have been listening carefully, for, after the list of thirty-two lecture titles had been read off, just as given above, he said, "These things sound good on paper but you will never find people willing to give the lectures."

This sort of helpless hopelessness is at the root of most of the troubles people have in getting worthwhile things done. Most of the motive in describing the origin of the St. Louis Plan is to show what can be done just by doing things instead of only talking about it. It is not hard to find good and willing lecturers. It is easy, but this can not be discovered, short of trying something.

Here is one example of a fine way to secure cooperation of industry, college and professional society for the improvement of chemical engineering education. There are many, many possible ways. The thing is to get action. In many cases, money is not of substantial importance. The chemical engineering profession is rich in talent, and has an inexhaustible supply of people who can improve chemical engineering education. The big need is for someone who cares, someone to lead the way.

Literature Cited

1. Kobe, K. A., *Chem. Eng. Progress*, **47**, No. 9, 48, (1951).
2. Stout, L. E., *Am. Soc. Eng. Educ.* Address (June 1951).

ADEQUACY AND STANDARDS OF ENGINEERING EDUCATION

ENGINEERING education in America was not developed after a preconceived plan. It evolved in parallel with . . . a country engaged in the development of a vast industrialization.

There were only a half dozen schools of substantial merit by 1866. . . . At that time, and for a generation to follow, a majority of practicing engineers were . . . men who through experience, observation, and study developed themselves to the point where they could cope with the technical problems of their time. Books began to appear; and with the development of laboratories . . . gave strength to the program of the colleges in systematization of technical knowledge.

With the passage of the Morrill Act in 1862 the means and urge to found in each state a program in the mechanic arts for the aid of manufacturers were at hand. From 1870 to 1896 there was rapid expansion of the number of schools to 110. . . . By 1910 the forms of curricula in the older branches of the profession were pretty well standardized. . . . No elevating influences appeared to be at work on other than the newer curricula, such as chemical and metallurgical engineering, until the first World War.

EDITOR'S NOTE

An important document in Engineering Education was presented to the Engineers' Council for Professional Development at its recent meeting in Boston by a special Committee on Adequacy and Standards of Engineering Education.

There, S. C. Hollister, chairman, summarized the thoughts of his committee on the status and trend in engineering. Here is a condensation of the full report, which can be read in the nineteenth annual report of E. C. P. D., page 17. Other members of the special group were C. S. Crouse, L. F. Grant, and M. D. Hooven.

Between the two World Wars the engineering schools developed programs in electronics . . . these . . . introduced new elements of strength in the increase of basic and applied science; and it was soon noticeable that they possessed more vitality and potential than the older programs. Yet most schools did little or nothing about these older curricula. . . .

Critical Evaluation of Factors in Engineering College Development

As one examines the history of the growth of engineering colleges and their development, certain features thereof are especially evident . . . many of the new schools had only a dim concept of their objective . . . pressure for staff expansion led to . . . keeping on recent graduates, and then allowing them to do their graduate work, if any, while teaching. In this way, there was a subtle influence of continuity of curriculum with little urge for re-evalua-

tion or vitality of concept of objectives. . . .

Coupled with these influences was the circumstance of ever-pressing financial problems. . . . Not a few administrators found themselves unable to pay salaries that would command talent already developed. . . . The deadening effect of obsolescence upon laboratory equipment, . . . had its part in gradual "standardization". . . .

. . . the number of practicing engineers without engineering college education was gradually diminishing.

From the earliest days the program of engineering education was limited to four years. . . . A very few schools added one or two years, with an additional degree. . . .

Probably the most significant single characteristic of the engineering educational field is that is has no generally accepted professional objective as a goal for the educational program. . . . There exists today a spectrum of objectives ranging from highly professional programs supported by strong science backgrounds to vocational programs in which only a moderate amount of science is included. . . .

Historically, applied engineering courses dominated the curriculum in the early years. Gradually the pattern of basic science courses was evolved and generally included. Shop courses were reduced to a minimum. From 1885 until the first World War, mathematics was stabilized in the older curricula, terminating with the calculus. . . . Except in chemical engineering, and in some cases of mining engineering, the amount of chemistry required has been limited to general inorganic chemistry.

The time requirement in physics has remained nearly constant in most curricula since about 1885. . . . In civil and mechanical engineering the amount of physics is limited to one year in most schools; and in many the same limit is found in electrical and chemical engineering. . . . the approach from the point of view of atomic and molecular structure is needed but wanting.

The time devoted to mechanics is similar in nearly all schools. . . .

Hydraulics used to be taught from the empirical standpoint. Between the two wars there was pressure, . . . for instruction in fluid mechanics. Some schools dealt sincerely with this proposed change; but many others simply changed the course name. . . .

While in chemical engineering thermodynamics has been taught with regard to interaction between the thermal and chemical circumstances involved, there has been little attention given to such matters in mechanical engineering. Today, a chemical engineer is not infrequently better trained for fundamental work in heat power than the mechanical engineer, in whose field heat power lies.

. . . instruction relating to engineering materials has developed into a . . . general discussion of their manufacture, and their mechanical properties . . . metallurgical aspects are lightly touched upon if at all. . . .

Factors of Major Significance in Curriculum Design

Many perplexing problems stem from the fact that the engineering college, . . . must evaluate hazily discernible future events. . . . there are certain specific features of the curriculum that can be accepted as most essential.

The first of these has to do with courses least likely to obsolesce. . . . it seems clear that instruction in the basic sciences . . . contributes the most sustaining part of the curriculum. . . . the greatest potential for future development in science and technology is to be found in mathematics. . . .

The third feature . . . has to do with the way applied courses are related to those in basic and applied science. . . .

Following the concept that the differentiating characteristic of the engineering function is the ability to utilize the sciences for the creative process of design and development of useful apparatus, structures or other works, the program should aim at the development and expansion of the imaginative process of creative thought. . . . We tend toward producing a literal-mindedness that is not compatible with creative imagination. . . .

Suggested Program

. . . While accrediting must be maintained as a part of the licensing procedure, it cannot be expected that accrediting of itself will achieve the improvement of schools . . . —unless two or more classes of schools were established and accrediting set up for each class. Your committee believes that such a scheme would neither be welcome nor desirable. Rather it believes that the engineering educational field has a great opportunity to study itself, . . .

One way to make such a study is to set up an agency that would study and report its findings. . . .

In some quarters the suggestion has been made that an overlay of graduate work is the answer to a need for stronger science content in the curriculum, and to a higher total level of achievement. Your committee believes that . . . the first degree in the field should be of a quality to suffice for the professional need of perhaps 80% of the graduates, and that truly graduate work should be reserved for the remaining few having special competence. . . .

. . . If engineering maintains professional stature, it will have to organize accordingly.

Finally, it becomes clear that there is going to be a shortage of engineers for many years to come. At such a time, in the national interest, it is of paramount importance that the best possible education in engineering be provided by our schools. . . .

ERRATA

"An Empirical Equation for Thermodynamic Properties of Light Hydrocarbons and Their Mixtures"

M. Benedict, G. B. Webb, L. C. Rubin, and L. Friend

Chem. Eng. Progress, 47, 609-620 (December, 1951)

An error was made in the above-titled article which involves literature citations in Table 14 on page 616, Table 16, page 617, Table 17, page 618, and Table 18, page 619. It involves all references from 19 up. The correct numbers are as follows:

p. 616, Table 14

System	Literature Cited as printed	Literature Cited correct
Methane-Propane	27	28
Methane-Isobutane	21	22
Methane-n-Butane	25	26
Methane-n-Pentane	31	32
Propane-n-Pentane	26	27
Methane-n-Hexane	28	29
Methane-Cyclohexane	28	29
Methane-Benzene	28	29
Methane-n-Decane	19	20
Natural Gas-Distillate	23	24
Absorption Oil	33	34
Methane-Ethylene	32,12	33,12
Methane-Ethane	12,24	12,25
Ethylene-Ethane	22	23
Propane-Isobutylene	29	30
Propane-n-Butane	20	21

p. 617, Table 16

Methane-n-Hexane	28	29
Methane-Cyclohexane	28	29
Methane-Benzene	28	29
Methane-n-Decane	19	20

p. 618, Table 17

Gas-Distillate System	23	24

p. 619, Table 18

Gas-Absorption Oil	33	34

The error was made, when another Literature Cited was inserted. All changes were made correctly in the text of the article but this was not caught when the tables were set.

CAST ALLOY REFERENCE SHEET

N. S. MOTT, Chief Chemist Metallurgist

The Cooper Alloy Foundry Co., Hillside, N. J.

ALLOY: HIGHLY CORROSION RESISTANT 20-29-2-3 CHROMIUM-NICKEL-MOLYBDENUM-COPPER ALLOY.

APPLICATIONS AND REMARKS: 20-29-2-3 alloy, commonly known as "FA-20," was developed primarily for resistance to sulfuric acid; however, it has an all-'round corrosion resistance which appreciably exceeds the widely used 18-8S Mo. It may be adapted to corrosive applications where the best in corrosion resistance is desired without extremes in cost, which is about 19 cents a pound in excess of 18-8S Mo. In addition to its use in handling sulfuric acid, it is necessary for handling hot and strong solutions of acid salts or chlorides, cold dilute hydrochloric acid, the stronger hypochlorite bleach solutions, and for many other more corrosive chemicals. It is cast into valves, pumps, fittings and many other types of castings.

DESIGNATIONS: ACI CN-7MCu COMMON FA-20 (or) TYPE 20 ALLOY.

CHEMICAL COMPOSITION RANGE: C < .07%; Cr 19-22%; Ni 28-30% Si < 1.5%; Mo 2-2.5%; Cu 3-3.5%.

MACHINABILITY: FA-20 machines quite readily giving crumbly brittle chips. Here the presence of copper greatly reduces toughness, a large detriment to the machinability of soft and ductile metals. Care must be taken to see that the alloy has been fully heat-treated before machining or segregation will produce a granular or uneven surface.

HEAT TREATMENT: FA-20 is subject to intergranular corrosion unless heat-treated. This consists of water quenching from 1950-2050° F. after holding for 1-3 hrs. depending upon thickness.

WELDABILITY: The presence of a relatively large amount of copper in the FA-20 alloy tends to make it brittle and red-short during welding, so great care must be taken. A preheat of 400° F. is required, and after welding, slow cooling is necessary to equalize stresses. To put carbides into solution for maximum corrosion resistance, the work should finally be water-quenched from 1950-2050°F.

MECHANICAL AND PHYSICAL PROPERTIES:

Tensile Strength, 1000 lb./sq.in.	75
Yield Point, 1000 lb./sq.in.	45
Elongation, %	40
Reduction in Area, %	45
Brinell Hardness	145
Charpy Impact (Std. Keyhole ft.lbs.)	15
Mod. of Elasticity (× 10^6 lb./sq.in.)	23
Specific Gravity	8.02

Melting Point	2650° F.
Specific Heat (B.t.u./(lb.)/° F.) 32-212° F.	0.11
Thermal Expansion (× 10^{-6} in./(in.)/° F.) 32-212° F.	7.8
Thermal Conductivity (B.t.u./sq.ft./° F./in.) 32-212° F.	145
Electrical Resistance (Ohms./cir. mil. ft.) @ 32° F.	580

CORROSION RESISTANCE

ACIDS	
Acetic 5%, 70 F	E
Acetic 5%, boiling	E
Acetic 80%, 70 F	E
Acetic 80%, boiling	E
Acetic Glacial, 70 F	E
Acetic Glacial, boiling	E
Benzoic 5%, 70 F	E
Boric 5%, 176 F	E
Chromic 10%, 70 F	E
Chromic 10%, boiling	E
Chromic 50%, boiling	G
Citric 5%, 70 F	E
Citric 25%, boiling	E
Citric 50%, boiling	E
Formic 5%, 70 F	E
Hydrochloric 1%, 70 F	E
Hydrochloric 1%, boiling	G
Hydrochloric, 5%, 70 F	N
Hydrochloric 5%, boiling	N
Hydrochloric 25%, 70 F	N
Hydrochloric 25%, 176 F	N
Hydrofluoric 48%, 70 F	P
Hydrofluoric 48%, 176 F	P
Lactic 5%, 70 F	E
Malic, all temps.	E
Nitric all concs., 70 F	E
Nitric 65%, boiling	G
Oleic all concs., all temps.	E
Oxalic 5%, boiling	E
Phosphoric 10%, 70 F	E
Phosphoric 85%, 70 F	E
Phosphoric 85%, boiling	G
Stearic concentrated to 200 F	E
Sulfuric 2%, 70 F	E
Sulfuric 2%, 176 F	E
Sulfuric 2%, boiling	E
Sulfuric 5%, 70 F	E
Sulfuric 5%, 176 F	E
Sulfuric 5%, boiling	E
Sulfuric 10%, 70 F	E
Sulfuric 10%, 176 F	E
Sulfuric 10%, boiling	E
Sulfuric 78% (60° Be), 176 F	E
Sulfuric 93% (66° Be), 70 F	E
Sulfuric 93%, 300 F	N
Oleum, 70 F	E
Mixed Acids 57% H_2SO_4, 28% HNO_3, 176 F	E

ALKALIES	
Ammonium Hydroxide, all concs.	E
Calcium Hydroxide Sat., 70 F	E
Calcium Hydroxide Sat., boiling	E
Sodium or Potassium Hydroxide, all concs., 70 F	E
Sodium or Potassium Hydroxide < 20%, boiling	E
Sodium or Potassium Hydroxide 30% boiling	E
Sodium or Potassium Hydroxide, Molten, 600 F	P

NEUTRAL AND ALKALINE SALTS	
Barium Sulfide, 70 F	E
Calcium Chloride 5%, 70 F	E
Calcium Sulfate Sat., 70 F	E
Magnesium Chloride 5%, 70 F	E
Magnesium Sulfate 5%, 70 F	E
Sodium Carbonate, all concs., 70 F	E
Sodium Chloride 5%, 70 F	E
Sodium Sulfate 5%, 70 F	E
Sodium Sulfide 5%, 70 F	E
Sodium Sulfite 5%, 70 F	E

ACID SALTS	
Alum 10%, boiling	E
Aluminum Sulfate 10%, 70 F	E
Ammonium Chloride 5%, 70 F	E
Ammonium Sulfate 10%, 70 F	E
Ammonium Sulfate 10% boiling	E
Ammonium Nitrate, all concs., 70 F	E
Stannous Chloride 5%, 70 F	E
Zinc Chloride 5% boiling	E

OXIDIZING ALKALINE SALTS	
Calcium Hypochlorite 2%, 70 F	E
Sodium Hypochlorite 5%, 70 F	E
Sodium Peroxide	E

OXIDIZING ACID SALTS	
Ammonium Persulfate 5%, 70 F	E
Cupric Chloride 1%, 70 F	G†
Cupric Sulfate 10%, 70 F	E
Ferric Chloride 10%, 70 F	G†
Ferric Sulfate, boiling	E
Mercuric Chloride 2%, 70 F	G†
Stannic Chloride 5%, 70 F	G†

WET AND DRY GASES	
Chlorine Gas Dry, 70 F	E
Chlorine Gas Wet, 70 F	F†
Sulfur Dioxide Dry, 575 F	E
Sulfur Dioxide Wet, 70 F	F
Sulfur Dioxide Solution, 70 F	F
Sulfur Dioxide Spray, 70 F	E
Hydrogen Sulfide Dry	E
Hydrogen Sulfide Wet	E

ORGANIC MATERIALS	
Acetone, 70 F	E
Acid Sludge (50% H_2SO_4), 200 F	F
Alcohol—Methyl and Ethyl	E
Aniline Hydrochloride, 70 F	G
Benzol, 176 F	E
Carbon Tetrachloride	E
Chloroform	E
Ethyl Acetate, 70 F	E
Formaldehyde, 70 F	E
Phenol 5%, boiling	E
Refinery Crudes	E
Trichlorethylene, boiling	E

PAPER MILL APPLICATIONS	
Kraft Liquor	E
Black Liquor	E
Green Liquor	E
White Liquor	E
Sulfite Liquor, 176 F	E
Chloride Bleach	E
Paper Makers Alum	E

PHOTOGRAPHIC INDUSTRY	
Humid Atmospheres	E
Cellulose Acetate	E
Acetic Anhydride	E
Acetic Acid + .1% H_2SO_4	E
Developers	E
Solutions Containing SO_2	E
Silver Nitrate, 70 F	E

FERTILIZER MANUFACTURING	
$H_3PO_4 + H_2SO_4 + HF$	E

PICKLING OPERATIONS	
H_2SO_4 + Dichromate, 176 F	E
$H_2SO_4 + HCl$, 176 F	F

CORROSIVE WATERS	
Acid Mine Water	E
Abrasive Acid Mine Water	E
Sea Water	E
Brackish Water	E

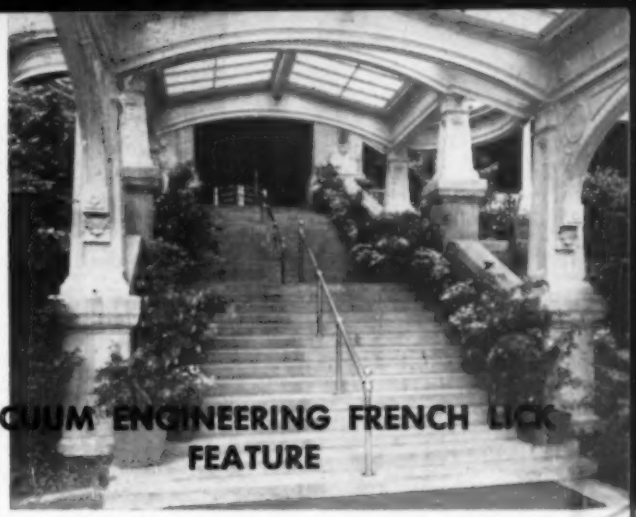
FOOD & ASSOCIATED PRODUCTS	
Brines	E
Edible Oils	E
Fats	E
Fatty Acid Distillation	E
Fruit Juices	E
Ketchup	E
Milk Pasteurizing	E
Vinegar and Salt, 70 F	E

RATINGS:

E—Excellent resistance. 0.005 max. in. per year of penetration. Corrosion so slight as to be harmless.
G—Good resistance. 0.005-0.012 in. per year of penetration. Satisfactory service expected; at most a slight etch.
F—Fair resistance. 0.012-0.120 in. of penetration per year. Satisfactory service under specific conditions. Light to moderate attack.
P—Poor resistance. 0.120-0.420 in. of penetration per year. Satisfactory for temporary service only.
N—No resistance. 0.420 min. in. of penetration per year. Rate of attack too great for any use.
†—Subject to pitting type corrosion.

No. 8

(EIGHTH OF A SERIES OF TEN)



VACUUM ENGINEERING FRENCH LICK FEATURE

A LONG hard technical look at vacuum engineering will feature the three-day French Lick national meeting scheduled for May 11-14. The program has sixteen papers scheduled for the three days in such a way as to make available free time for discussion and personal investigation of the new ideas and techniques. Emphasis on industrial uses and problems is promised by the fact that many of the authors will discuss plant applications.

Wheaton W. Kraft, vice-president of the Lummus Co., is technical program chairman and has scheduled four papers for each of two sessions on the opening day, Monday. However, for Tuesday and Wednesday, the afternoons have been left open so that engineers can arrange for individual conferences with the leaders in vacuum technology.

This French Lick session follows, in many respects, the philosophy which has been a distinct feature of Institute planning, resort-type meeting. At them, engineers are away from plants and offices in an atmosphere of informal cordiality and can devote their energies solely to the business at hand.

This is the second monotheme meeting, but it is not the first resort meeting. The individual topic was successfully dealt with at White Sulphur Springs last year and its success lent encouragement to making the French Lick meeting a similar single-purpose symposium.

Technical Program

The four technical sessions will be under the direction of John R. Bowman, head, department of research in physical

(*Continued on page 54*)

SYMPOSIUM ON VACUUM ENGINEERING

Monday Morning

9:30 A.M. **Opening Remarks.**—*Wheaton W. Kraft, Technical Program Chairman.*

TECHNICAL SESSION No. 1

John R. Bowman, presiding

9:45 A.M. **Evaporation Habits of Liquids in Vacuum.**—*Kenneth Hickman, consultant, and D. J. Trevoy, Kodak Research Laboratories, Rochester, N. Y.*

10:15 A.M. **Rectification at Reduced Pressures.**—*Harding Bliss, A. M. Eshaya, and N. W. Frisch, Yale University, New Haven, Conn.*

10:45 A.M. **A Survey of Gauges for Measurement of Low Absolute Gas Pressures.**—*Richard B. Lawrance, Applied Physics Dept., National Research Corp., Cambridge, Mass.*

11:15 A.M. **Outgassing Properties of Materials Used in Vacuum Systems.**—*Benjamin B. Dayton, Vacuum Equip. Dept., Distillation Products Industries, Rochester.*

TECHNICAL SESSION No. 2

Karl H. Hackmuth, presiding

2:00 P.M. **Pressure Drop for High Vacuum Flow of Air Through Annular Sections.**—*Charles R. Alancraig and LeRoy A. Bromley, Dept. of Chemistry and Chem. Eng., University of California, Berkeley, Calif.*

2:30 P.M. **Problems of the Transport of Vapors Under Residual Gas Pressures Below 1 mm/Hg.**—*Georg Wilhelm Oetjen, E. Leybold's Nachfolger, Koln-Bayental, Germany.*

3:00 P.M. **A New Synoptic Presentation of the Characteristics of High Vacuum Vapor Pumps.**—*Richard B. Lawrance, Applied Physics Dept., National Research Corp., Cambridge, Mass.*

3:30 P.M. **Selection of Vacuum Pumping Systems.**—*L. W. Hull, F. J. Stokes Machine Co., Philadelphia, Pa.*

4:00 P.M. **Purification of Vacuum Pump Lubricating and Sealing Oils.**—*Finley M. Steele, The Hilliard Corp., Elmira, N. Y.*

Tuesday Morning

TECHNICAL SESSION No. 3

Brymer Williams, presiding

9:30 A.M. **Observations on the Design and Operation of High Vacuum Systems.**—*C. Kerby Stoddard and W. E. Mooz, National Lead Co., Titanium Div., South Amboy, N. J.*

10:00 A.M. **Vacuum Facilities for the Study of Supersonics Flow.**—*G. J. Maslack, Dept. Chem. Eng., Institute of Engineering Research, University of California, Berkeley.*

10:30 A.M. **Flow Visualization in High Vacuums.**—*R. G. Folsom, Mech. Eng. Dept., University of California, Berkeley.*

11:00 A.M. **Altitude Test Facilities for Aircraft Engine Research.**—*Bruce R. Leonard, Equip. Eng. Sect., and Jean N. Vivien, Process Systems Eng. Sect., Nat. Advisory Comm. Aeronaut., Lewis Flight Propulsion Lab., Cleveland, Ohio.*

Wednesday Morning

TECHNICAL SESSION No. 4

Edgar L. Piret, presiding

9:30 A.M. **High Vacuum Technique—the Incurred Savings When Applied to Concentration.**—*E. J. Kelly, Concentrator Dept., Carrier Corp., Syracuse, N. Y.*

10:00 A.M. **Multi-Stage Ejectors for High Vacuum.**—*V. V. Fondrk, Product Engr., General Apparatus Eng. Div., Elliott Co., Inc., Jeannette, Pa.*

10:30 A.M. **Corrosion Problems in Steam Jet Vacuum Equipment.**—*David H. Jackson, Vice-President, Croll-Reynolds Co., Inc., New York.*

11:00 A.M. **Flash Vaporization—Analysis of Fluid Mechanical and Mass Transfer Problems.**—*R. R. Hughes, H. D. Evans, C. V. Sternling, Shell Development Co., Emeryville, Calif.*

Left: W. T. Nichols, Dir. General Eng. Div., and F. P. LaBelle, Chief Chem. Engr., Phosphate Div., both with Monsanto Chem. Co. Right: George D. Bieber, Eastern Gas and Fuel Associates, and C. H. Bronson, Tennessee Corp.

SOUTH ON THE RISE

ATLANTA, Ga., was headquarters for chemical engineers, last month, when more than 700 went to the city for a national meeting of the American Institute of Chemical Engineers. An evenly balanced program drew a representative group of the chemical engineering profession, for management, production, research, and development were all nicely mixed together for a solid, factual, work-a-day meeting.

And this was well, for the South had something to show and to talk about for every branch of the chemical field. And talk they did; after a day of technical papers in the city itself, the engineers dispersed to the famous restaurants, and there, in the informal atmosphere, talked over the growing chemical potential of the South. And sooner or later in background music or in conversation one would come upon the theme song of the South of today, "The South Shall Rise Again." The title is indicative of the mood of the area, and the chemical industry is one of the South's natural leaders in a growing economic strength. The complete technology of the chemical field is being brought rapidly to bear in the creation of new industries, natural for the region, and designed to serve a market which is also rapidly growing. Research laboratories and personnel are hammering away at the economic problems of the South, and those who took time to consider the direction of the meeting, saw at once that much of the discussion and many of the questions in informal corridor conferences applied to local and territorial plants and problems.

As for the meeting itself, a full complement of technical men turned out with a final attendance of 704. Only three regional-type meetings have been larger. Prior to the meeting (there had been no local section in Atlanta), but during the Council meeting on Sunday, a charter was granted for the local group.

Social events were typical for a national meeting, and the rumor finally reached the men at the end of the meeting, that the women's program was one of the most interesting and strongest of recent years. The ladies paid visits to local historical and cultural points, antebellum homes noted for their adherence to the southern style of architecture and appointments, and the cyclorama in Grant Park (not *that* Grant, Suh!).

The technical program featured, beside the fundamental technical sessions, two innovations so far as programming for an Institute meeting is concerned. The first was a symposium on "What's New in Process Equipment," of which D. M. Considine of the Brown Instrument Division, of Minneapolis-Honeywell Co., acted as chairman. The program was designed to cover mixing and instrumentation developments. To facilitate the understanding of what the authors were describing and discussing in their papers, a display of equipment was arranged at the side of the meeting-hall and this was received with some enthusiasm by those who attended the meeting. A questionnaire on the type meeting was distributed and preliminary results indicate that those who were there were overwhelmingly in favor of its continuation, and that the exhibits of models and diagrams to augment the papers were helpful and should be continued.

Another innovation in the technical program was under the direction of Richard M. Lawrence, general development department, Monsanto Chemical Co., and entailed a symposium on "Chemical Market Research Problems and Practices." This, too, was in two parts, the first or morning session covered research problems; the second or

(*Continued on page 37*)

Top Row: M. E. Clark, Wyandotte Chemical Co.; G. D. Bieber, Eastern Gas and Fuel Assocs.; H. W. Yeagley, Monsanto Chemical Co.; C. W. Berl, Hercules Powder Co.; S. D. Kirkpatrick, McGraw-Hill Pub. Co. Bottom Row: M. W. Leland, Shell Chemical Corp.; Parker Frisselle, Dow Chemical Co.; J. H. Sprague, Monsanto Chemical Co.; R. M. Lawrence, Monsanto Chemical Co., who presided at the symposia on Chemical Market Research at the Tuesday morning and afternoon sessions, together with the authors of papers presented there.

Top: Mr. and Mrs. Herschel H. Cudd. Bottom: President and Mrs. W. I. Burt at the banquet on Tuesday evening.

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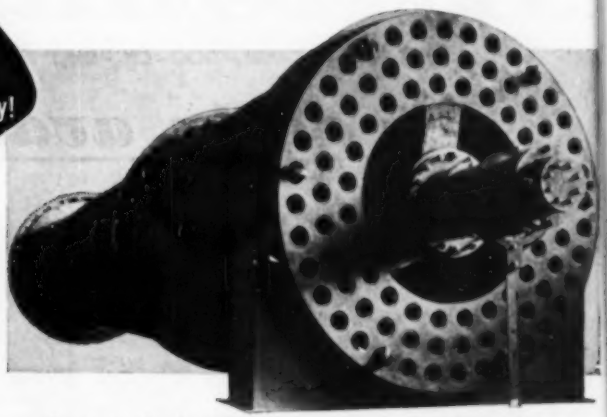

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ATLANTA STORY

(*Continued from page* 34)

afternoon session covered research case histories. It was for his presentation of a paper at this morning session that Parker Frisselle, manager of market research, Dow Chemical Co., Midland, Mich., was judged the winner of the "presentation" contest held at all A.I.Ch.E. meetings. Comments at the meeting indicated that the two innovations in the programming were distinct successes, and that much would be gained if the Institute undertook to retain such programming.

The other technical sessions were presided over by H. H. Cudd, head of the department of chemical sciences at Georgia Institute of Technology; the Wednesday morning meeting on "Chemical Engineering Fundamentals," was presided over by J. L. Franklin, resident associate, Humble Oil & Refining Co.; the Wednesday afternoon session was in the hands of H. E. O'Connell, process design supervisor, Ethyl Corp.

Technical Sessions

In one of the technical papers, George E. Barker and Prof. R. R. White of the University of Michigan, reported on their continuing studies on the use of cation exchange resins as catalysts for organic reactions. As a basis of study, the authors chose the formation of ethyl acetate and *n*-butanol from *n*-butyl acetate and ethanol. The catalyst used was a nuclear sulfonic acid resin and the reaction was chosen because of its commercial importance in modifying the esters of various vegetable oils. The authors found three mechanisms to correlate their experimental data and

(*Continued on page* 42)

Top: Harold Murdoch, Chemical Consultant.
Middle: E. A. Winter, Proj. Div., Tennessee Corp.
Bottom: F. H. Bell, Chairman, Entertainment Comm.

Robert T. Sheen, President, Milton Roy Co., delivering his paper.

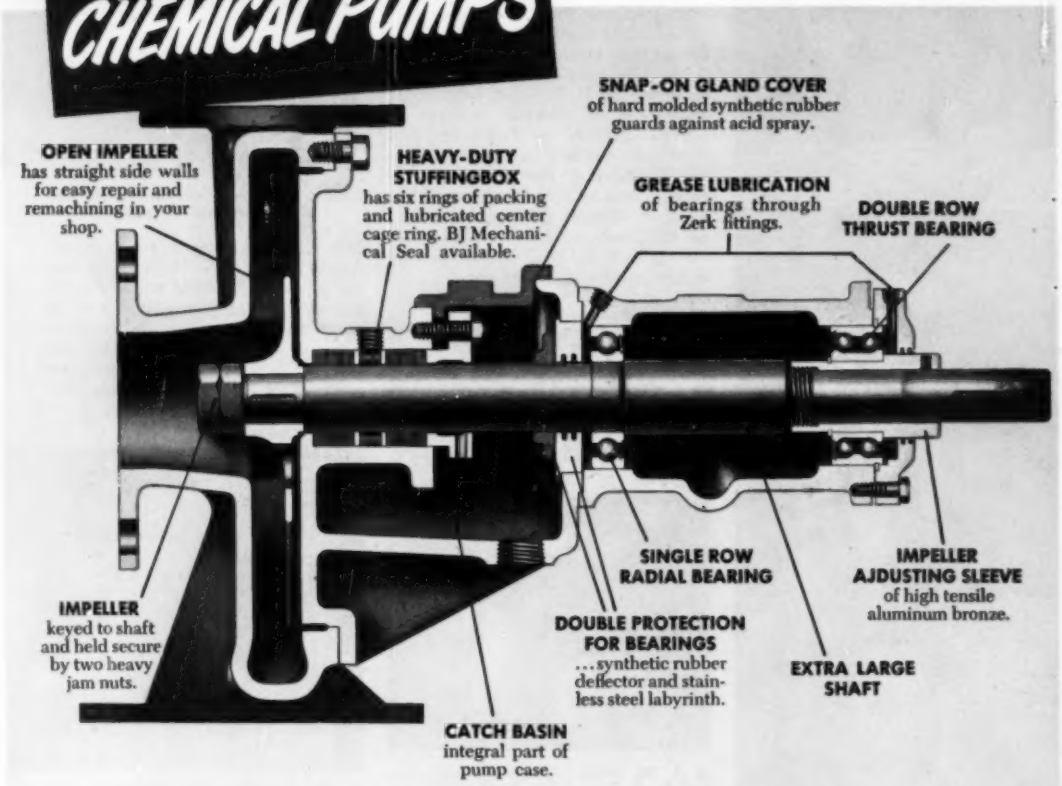
▲ A. W. West, Monsanto Chem. Co., and A. P. Tait, Alloy Steel Prod. Co., both members of the Publicity Committee, discuss a proposed newspaper release.

A group from the Atlanta meeting. Picture taken in front of the Blue Goose Staff House where the group had lunch. ▼

D. M. Considine, Minneapolis-Honeywell Co., Brown Instr. Div., Mgr. Tech. Sect., and Oren D. Myrick, Davison Chemical Co. Mr. Considine was chairman of the symposium on "What's New In Process Equipment." He is shown above demonstrating some instruments which were displayed to illustrate equipment discussed in the technical papers.

NEW BJ CHEMICAL PUMPS

Here are chemical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of hard molded synthetic rubber guards against acid spray.
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EXTRA LARGE SHAFT
CATCH BASIN
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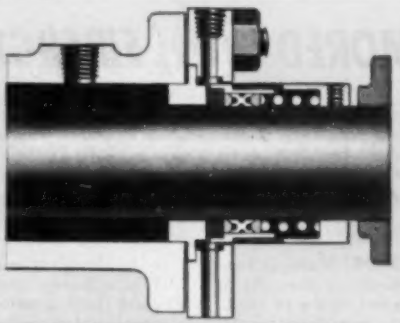
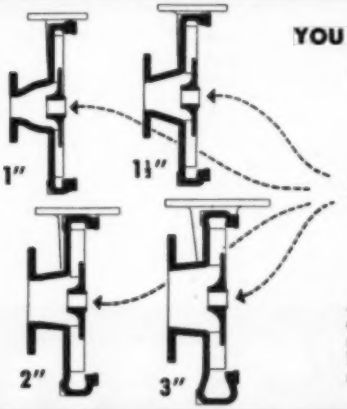
- *Grease lubrication* gives bearings greater protection against acid fumes. Deflector and labyrinth provide double protection against liquid entrance.
- *Cored passages* through impeller web keep stuffingbox under suction pressure.

pumps engineered to your demands...

You—the chemical pump user—dictated the design of these new BJ Chemical Pumps. Before Byron Jackson engineered these new BJ models, chemical pump users were asked what features were wanted most. Now these improved features are yours in the new BJ Chemical Pumps. Four pump sizes are available (1", 1½", 2" and 3") with capacities to 450 gpm and heads to 100 feet.

BJ Mechanical Seal also available for protection against leakage. BJ's Type "A" Mechanical Seal is designed especially for the particular demands of chemical pumping. It replaces the packing and provides positive protection against leakage to the bearings or contamination of the pumped liquid. All major parts of this BJ-designed seal are effectively isolated from contact with pumped liquid. Available as special construction, the BJ Mechanical Seal will save you maintenance time and money by eliminating frequent repacking.





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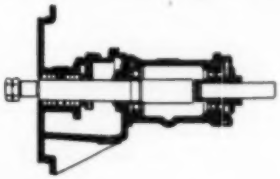

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THE BODY: Solid Lapp Porcelain, thoroughly vitrified, of *zero* porosity, acid proof through and through. Widely used for severe corrosion service and where metallic contamination cannot be tolerated.

THE ARMOR: Multiple layers of heavy fiberglass woven cloth, impregnated with a special modified phenolic resin of high adhesive strength for bonding to porcelain and between layers of cloth. Fiberglass cloth patterns are heavily coated and fitted around the porcelain, seams overlapped, and oven-cured to full strength and permanently knit to porcelain. Armor shell fully covers porcelain, running end-to-end and *under* flanges.

PERFORMANCE: Armor shell acts as a cushion to protect against impact damage in handling or operation. Insulates porcelain against sudden thermal shock. *Most important,* shell in its own right is homogeneous and tough—will hold line pressures even though porcelain is cracked or broken. Safety to personnel and prevention of loss of product are assured by at least temporary control of lines in case of accident.

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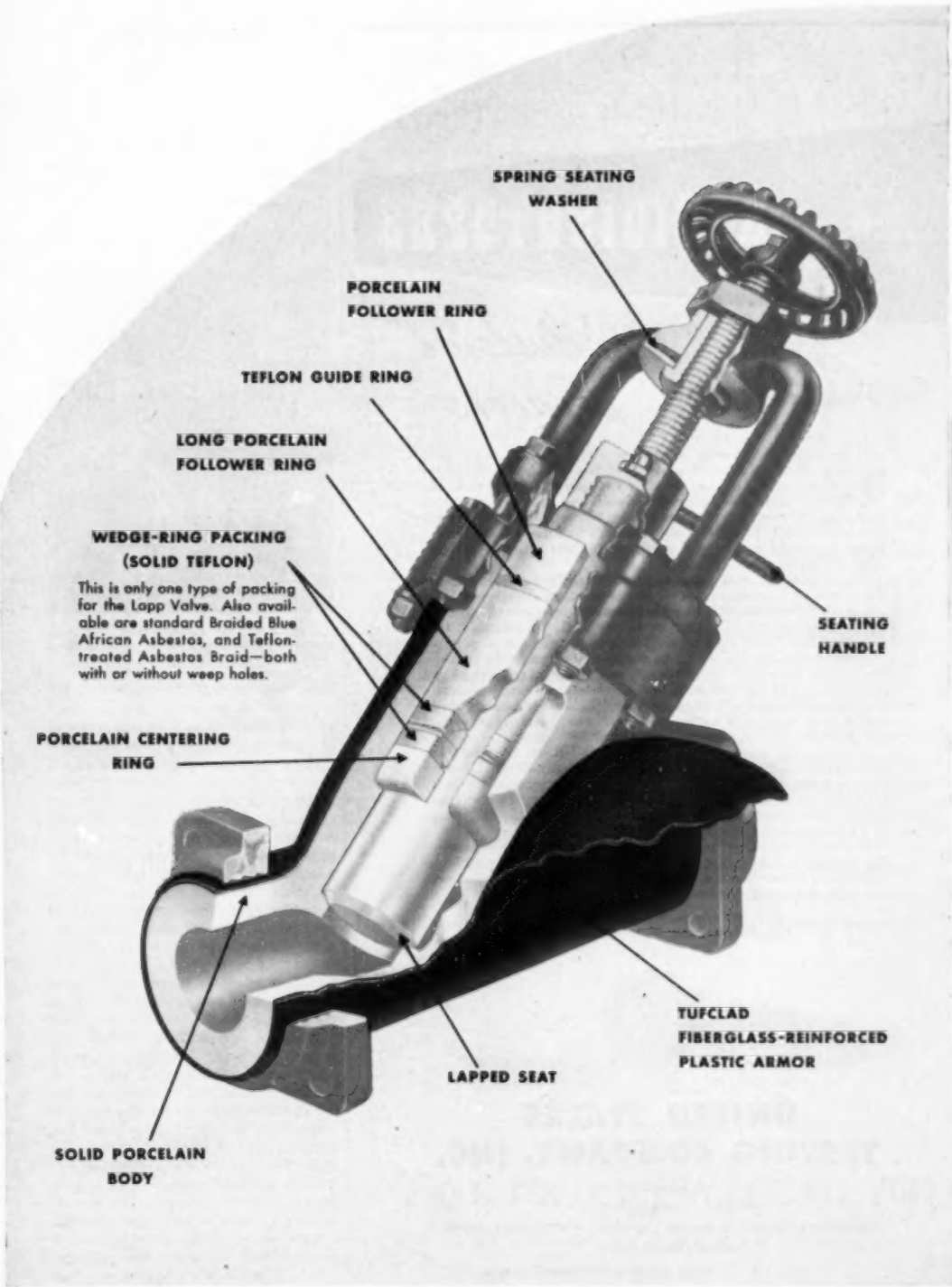
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PORCELAIN FOLLOWER RING
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WEDGE-RING PACKING (SOLID TEFLON)
This is only one type of packing for the Lapp Valve. Also available are standard Braided Blue African Asbestos, and Teflon-treated Asbestos Braid—both with or without weep holes.
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PORCELAIN CENTERING RING
TUFCLAD FIBERGLASS-REINFORCED PLASTIC ARMOR
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All branches of industry may now apply Radioisotope techniques to their production and research problems. The United States Testing Co., Inc. has recently expanded its applied Radioactivity Division to undertake more and varied sponsored Industrial Research projects involving the utilization of Radioactive materials. The integrated research facilities of the United States Testing Co., Inc. are available for the solution of technical problems by this versatile tool.

The investigation of a great variety of surface phenomena on a research and production scale has been successfully completed using the Radioisotope technique. Radioisotopes have proven to be an unsurpassed research tool in the study of diffusion, friction, kinetics, and organic mechanisms. Process and product control, determination of the homogeneity of mixtures containing important minor constituents, and other examples of the measurement of the flow or transport of materials are numerous. The Isotope Dilution Technique is finding a wide field of application as an analytical technique which yields quantitative data yet employs only qualitative techniques.

A competent research team is available for the consideration and execution of your work. The applied Radioactivity Division is under the direction of Dr. Charles E. Crompton, formerly with the Isotope Division of the Atomic Energy Commission, whose varied experience in this field dates back to the early days of the Manhattan Project.

We invite inquiries from all segments of industry regarding the potential application of Radioisotopes to their problems. Sponsored research projects may be carried out at modest cost and without capital investment to client.

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ATLANTA STORY

(*Continued from page 37*)

eliminated any single mechanism for the reaction. Rate, they found, was controlled by diffusion and chemical reaction and the correlation took the form of a second-order kinetics equation.

A method of determining pipe-line sizes for non-Newtonian fluids was described by G. E. Alves of the Du Pont Co., Inc., on Monday morning, along with D. F. Boucher of the same company, and Prof. R. L. Pigford of the University of Delaware. He presented information on various classifications of non-Newtonian fluids plus experimental data on four representative materials. A design procedure was outlined for steps to be taken in the sizing of pipe-line and computing pressure drop for viscous materials. The authors ended their paper with some information on the selection of pumps for such viscous materials. They said that for thixotropic materials centrifugal pumps could be used which open impellers where particle size is large or where particles would tend to clog small passages in a closed impeller. If a centrifugal pump is used, its high rate of shear may reduce the viscosity of the material and cause degradation and dispersion; then they suggest the use of diaphragm pumps or piston pumps. Rotary-gear pumps can be used for solutions of these types, but the authors advise against this type for suspensions because of rapid wear. For pumping dilatant materials, they stated, it is necessary to use a slow-moving, low-rate-of-shear pump in order to keep the viscosity of the material as low as possible. Pumps of this type are—diaphragm, squegee types, piston and screw pumps. Blow cases, they also said, can

(*Continued on page 46*)

Texas and the South—Suh! H. J. Marwil, Phillips Petroleum Co., Borger, Tex.

$ulfur

by-product with a big dividend

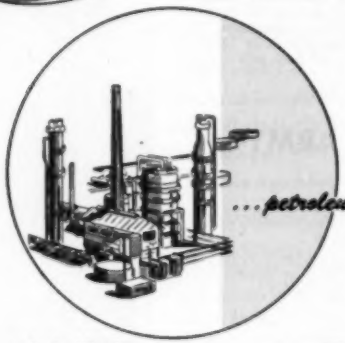
recovered with

FOSTER WHEELER

EQUIPMENT

...from oil and gas fields

H_2S content of sour gas converted to elemental sulfur. A Foster Wheeler sulfur recovery plant in one location is producing over 300 tons/day of elemental sulfur.

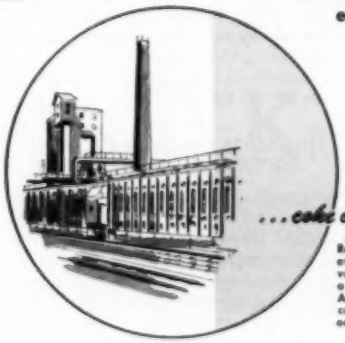


...petroleum refineries

H_2S gases previously "flared" and the sulfur wasted, now recovered. Two Foster Wheeler sulfur recovery plants for this service now under construction.

The unprecedented demand for Sulfur has reached a point where the world's available supply is seriously threatened. Thus, the need to find new sources for this vital element becomes one of the major items on today's agenda for full-scale production for both defense and civilian needs.

Fortunately, there is a great new source. Instead of allowing it to vanish into thin air, Sulfur is being recovered profitably from H_2S bearing gases with Foster Wheeler equipment. A quarter million tons of Sulfur per year will be recovered by Foster Wheeler plants installed or now under construction.



...coke ovens

Removal of H_2S from coke oven gas not only enhances the value of the gas but provides a source of elemental sulfur. A Foster Wheeler sulfur recovery plant is in operation on this service.

FOSTER WHEELER

165 BROADWAY, NEW YORK 6, N. Y.

NEW INDIAN DRUG AND DYE PLANT

View above of new dye and pharmaceutical plant of Atul Products, Ltd., in Bulsar, India. The new establishment is a joint Indo-American enterprise between American Cyanamid Co. and Kasturbhai Lalbhai, Indian textile manufacturer. The plant will produce azo and sulfur dyes, and sulfa drugs. Aureomycin is planned for production soon. The plant was built at a cost of $3,500,000 and will have a capacity of 4,000,000 lbs. of dyes annually.

CHEM. ENGRS'. CLUB FOR ARMY SPECIALISTS

THE first organizational meeting of a group of Army enlisted men who by educational or professional background qualify as chemical engineers was recently held at the Army Chemical Center, Md., where these men are assigned.

The idea of forming a club of such men originated in a letter from two of the soldiers, Cpl. John M. Ward and Pfc. Kenneth L. Vander Voort, to Thomas H. Chilton, then President of the American Institute of Chemical Engineers and technical director of the development engineering division of the Du Pont co.

Dr. Chilton encouraged them to organize a Chemical Engineers' Club at this installation, with the eventual idea of forming a local chapter of the American Institute of Chemical Engineers.

A copy of Dr. Chilton's letter was sent to Prof. H. L. Johnstone of the University of Illinois and to Dr. A. P. Colburn, Provost, University of Delaware, both of whom are members of A.I.Ch.E. They brought the matter to the attention of the Chemical Center's Commanding General, Brig. Gen. William M. Creasy (also a member) who has since taken a personal interest in the group.

The newly formed club plans monthly meetings with talks by guest speakers on subjects of interest to the members. Approximately 70 enlisted men attended the organizational meeting.

Such enlisted specialists are part of the Army's scientific and professional program, designed to utilize the civilian background and technical training of enlisted men by giving them specialized assignments. More than 800 of these military specialists in different fields are assigned to this installation, which is the Research and Development Center of the Army's Chemical Corps.

CHEMICAL SAFETY DATA SHEET AVAILABLE

Chemical Safety Data Sheet SD-43, "Acetaldehyde," has recently been issued by the Manufacturing Chemists' Association, Inc. This publication summarizes the physical and chemical properties of acetaldehyde, points out its hazards and recommends precautionary measures for its handling and use. The booklet contains detailed first-aid instructions, as well as useful medical data supplied by the Medical Advisory Committee of the MCA.

This data sheet of 15 pages may be purchased at 30 cents a copy from the Manufacturing Chemists' Association, Woodward Building, 15th & H Streets, Washington 5, D. C.

FOURTH O.R.N.L. SUMMER SESSION

The Fourth Annual Oak Ridge Summer Symposium, scheduled for Aug. 25-29, 1952, will be subtitled "The Role of Atomic Energy in Agricultural Research." The symposium is being given by the Oak Ridge Institute of Nuclear Studies and the Oak Ridge National Laboratory under the sponsorship of the University of Tennessee-Atomic Energy Commission Agricultural Research Program.

A number of sessions will be devoted to plant and animal studies with atomic research tools. Other lectures will deal specifically with Carbon-14 studies in both plants and animals.

Additional information may be obtained from the University Relations Division of the Institute, P.O. Box 117, Oak Ridge, Tenn.

TITANIUM PRODUCED AT FORMER MAGNESIUM PLANT

Titanium is now in limited production at Henderson, Nev., in a plant built during World War II to turn out magnesium. A chunk of the sponge-like titanium metal that will be cast into ingots is being examined by George W. Llewellyn (left) of The H. K. Ferguson Co., industrial engineers and builders, and R. P. Smith, plant manager at Henderson for Titanium Metals Corporation of America, a subsidiary of National Lead Co. and Allegheny Ludlum Steel Corp.

A portion of the one-time magnesium plant is being rehabilitated to expand production of this metal to 3600 tons annually. The new metal is needed in the defense program, where it is used for atomic energy, jet aircraft and other essential applications.

(More News on page 55)

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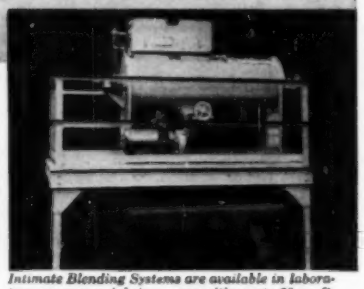

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SPROUT-WALDRON
INTIMATE BLENDING

210

ATLANTA STORY

(*Continued from page 42*)

be used for any type of material and care must be exercised to prevent air from entering the line since it is difficult to separate air from plastic and viscous materials.

H. L. Baker, Jr., Chairman of the Hotels and Meeting Rooms Committee.

An important study in mass transfer was also given at Atlanta by Stanley Seltzer and Brymer Williams, both of the University of Michigan. In their introduction to the subject the authors stated that while mass transfer between phases is one of the most common of the unit operations, it is one of the least understood. They undertook an investigation on one piece of equipment—a liquid-liquid extraction spray column—and tested the effect of design variables on the mass-transfer coefficient in the transfer area. Conclusions reached by the authors were that under certain conditions the variations of the coefficient K were insignificant in comparison with the variation in the unit mass-transfer area per unit volume of transfer equipment. They stated that mass-transfer investigations must therefore include studies of factors influencing the transfer area if they are to have full value in equipment other than that studied.

"Performance on Perforated-Plate Distillation Columns" was reported by D. S. Arnold, C. A. Plank and E. M. Schoenbrun of North Carolina State College. The authors stated that perforated plate or sieve-plate columns have been in use in the chemical industry for many years but little information has appeared in the chemical literature on which to base design or performance predictions. The authors stated at the end of their study that in the design of perforated-plate columns for distillation columns or absorption operations, pressure drop across trays under various operating conditions, can be predicted. In the calculations, the authors make use of an empirical correction factor and presented a chart on correction factors permitting measurement of pressure drop within 5 per cent for values of liquid mass flow rate of 1000 gals./(hr.)(sq.ft.).

(*The End*)

Girdler Process News

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For the first step in our planning—obtaining factual data for evaluation—Girdler offers cost-plus contracts covering preliminary engineering. This includes process recommendations, flow diagrams, general equipment specifications, plot plans, cost estimates, and operating cost data. Such coordinated data simplifies planning and assures sound decisions.

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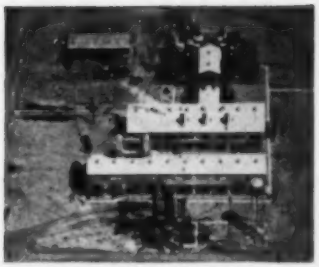
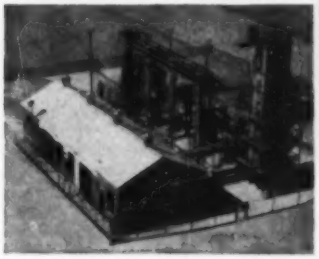
Need engineering ... construction assistance?

Girdler's Gas Processes Division designs and builds plants for the production, purification, or utilization of chemical process gases; purification of liquid or gaseous hydrocarbons; manufacture of organic compounds. Write for Booklet G-35. The Girdler Corporation, Gas Processes Division, Louisville 1, Ky. District Offices: San Francisco, Tulsa, Atlanta, New York. In Canada: Girdler Corp., of Canada Limited, Toronto.



SULPHUR FROM SOUR GAS

At the Wyoming plant of Texas Gulf Sulphur Company, sour gas, containing about 30% hydrogen sulphide is used as a source of scarce sulphur. The hydrogen sulphide is separated from the gas and converted to sulphur, and the purified gas is sold for normal use. Prime contract for engineering and constructing the facilities, including gas purification plant, sulphur recovery plant, water softening plant, sulphur storage and loading equipment, and buildings, was handled by The Girdler Corporation.



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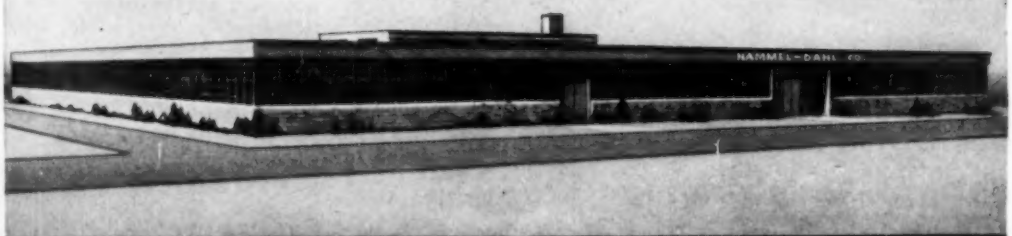

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1 • *CAPRYL ALCOHOL.* A new booklet on the properties of capryl alcohol from Rohm & Haas Co. Includes physical properties of two available grades, outlines chemical reactions in organic synthesis, including esterification, dehydration, dehydrogenation, etc.

2 • *SURFACE-ACTIVE AGENTS.* Nonionic surface-active agents of the polyoxyalkylene fatty ester type, called Monisols, described in a technical bulletin from Alrose Chemical Co. A group of six agents is described, all oils or soft waxes. Contains emulsifiers, spreading agents, thickeners, plasticizers, wetting agents, etc. Light colored, acid number does not exceed 6.0. Data on physical properties, uses in agriculture, fuel oils, plastics, metal processing, textile dyeing are discussed.

3 • *WET STRENGTH RESIN.* A new resin Aminoplast to impart greater wet strength to paper by Plaskon. Company claims 33% more wet tensile strength than equal amounts of urea resins. Soluble and may be added to equipment by any standard method.

4 • *BUTYL CARBITOL.* Technical bulletin on diethylene glycol monobutyl ethers from the Carbide & Carbon Chemicals Co. Covers physical and chemical properties, shipping data, applications, etc.

5 • *POLYVINYL CHLORIDE.* Resin by B. F. Goodrich Chemical Co. which will process at temperatures 10° to 15° lower than comparable polyvinyl chlorides. New service bulletin gives laboratory data showing the resin, though lower in molecular weight, causes no significant sacrifice in physical properties.

6 • *ABRASIVE GLUE.* A high-strength glue for binding abrasives to metal polishing wheels from Hanson-Van Winkle-Munning Co. The glue has improved water absorption characteristic combined with viscosity, flexibility, and strength characteristics designed especially for bonding abrasives to metal wheels.

7 • 8 • *PLASTICIZER.* For vinyl chloride and other vinyl copolymer resins, Rohm & Haas announce a new primary plasticizer (7) of low volatility. Has high molecular weight and employed alone or with blends of plasticizers. Dark appearance makes it suitable for filled and pigmented compounds. (8) Is for similar vinyl compounds but is light in color and closely parallels dioctyl sebacate. Complete information and physical data available.

9 • *CELANESE CHEMICAL CATALOG.* The 1952 catalog from the chemical division of Celanese Corporation of America on physical and chemical properties of aldehydes, ketones, solvents, acids, and glycols. Information on uses and applications of the compounds as well as shipping, handling, and toxicological data.

10 • *VINYL ACETATE POLYMERS.* National Starch Products, Inc., folder on vinyl acetate polymers and copolymers in solution and emulsion form. Properties of five typical solutions and emulsions; table of solution properties includes solids content, viscosity, film hardness and intrinsic

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viscosity. Application of the solutions to heat seal and solvent reactivating coatings, high gloss coatings, adhesives, binders for paper, fibers, cork and paper, and textile sizes.

11 • ***REINECKE SALT.*** For separating amino acids, precipitating and identifying organic bases, Reinecke Salt available from Jasonols Chemical Corp. Bulletin gives formulas, methods of preparation, uses, physical data, and references in the technical literature.

12 • ***MOLYSULFIDE.*** An extensive data book on the use of molybdenum sulfides as lubricants. Bulletin is from Climax Molybdenum Co. and lists the use of material as an effective lubricant under operating conditions where normal lubricants have failed. Covers all industry, application range from lubrication of ski bottoms to lubricating tapered plug-type valves handling concentrated sulfuric acid. Reference index lists materials and applications.

14 • ***MOLD RELEASE AGENTS.*** Data sheets from Dow Corning Corp. for foundries and mold-making industries on the use of silicone release agents. For use in the rubber and plastic molding industries as well as metal casting. Covers three different parting agents.

15 • ***MILDEWPROOFING AGENTS.*** From Witco Chemical Co. a 12-page technical service report on 8% copper naphthenate and other chemicals for mildewproofing irons in accordance with Armed Services specifications. Lists the specifications that call for mildewproofing.

16 • ***FLOTATION AGENT.*** A new synthetic flotation frother for the metallurgical and mining industries by Dow Chemical Co. Developed in response to the industry's need for a noncollecting frothing agent. It is returned to the flotation circuit in water-recovery systems owing to its solubility.

17 • ***3-AMINOPROPANOL.*** From American Cyanamid Co., 3-aminopropanol in trial lots for evaluation by the chemical and allied industries. For the soap and other surface-active agent field, dyestuffs, pharmaceuticals and resins. New product bulletin describing properties and experimental lots available.

18 • ***PLASTIC PAINT.*** A bulletin describing the characteristic applications and methods of use of Corrosite for painting metals, concrete, brick, stone, etc. A mixture of vinyl resins blended with plasticizers and solids. Applied by spraying, brushing, or dipping. Uses, applications, precautions, etc., are all described in the technical bulletin. The Corrosite Corp.

19 • ***PERSULFATE BIBLIOGRAPHY.*** From Buffalo Electro-Chemical Co., Inc., a collection of literature references pertaining to various uses of persulfates. Bulletin has collected references to persulfate from 1907 to 1950 and presents a broad panorama of the varied and many uses to which persulfates are put.

BULLETINS

21 • ***CHEMPUMP.*** A seal-less centrifugal pump, one piece motor and pump unit, with a magnetic drive and no mechanical seals or stuffing boxes. The fluid being handled circulates freely in the rotor chamber, isolated from the motor windings by a stainless steel cylinder inserted in the stator. Lubrication provided by the fluid. Only one moving part, a combined rotor-impeller. Materials of construction available for most corrosion resistance requirements. Chempump Corp.

22 • ***ALLEGHENY METAL.*** Extensive brochure on the use of Allegheny stainless steel in the chemical process industries. Covers use of material in acid manufacture, general process industries, plastics, pharmaceutical dyes, etc. Corrosion resistance chart, plus information on available forms, etc. Allegheny Ludlum Steel Corp.

23 • ***MATERIAL HANDLING.*** Equipment catalog from Jeffrey Mfg. Co. on material handling and process equipment for all industries. Covers electric vibrating feeders, bin check valves, level indicators, mechanical feeders of all kinds, crushers, pulverizers, shredders, etc. Illustrated.

24 • ***AUTOCLAVES.*** Autoclave Engineers, Inc., with a catalog on high pressure equipment. Covers autoclaves, valves, and fittings. Autoclaves range from 1 l. through 20 gal. Detailed information on a new con-

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tinuous hydrogenation unit. Article on safety in high pressure autoclaves and high pressure valves, fittings, etc.

25 • FLOW METERS. Barton Instrument Corp. describes in a comprehensive fashion flow meters made by this company. Feature a rupture-proof differential pressure unit with a sensitive bellows for an actuating element. A torque-tube drive is employed to transmit movement of the bellows to a panel pointer mechanism. Accurate to 0.5 per cent of full differential pressure range at any point on the chart or scale.

26 • EXCHANGERS. Henry Vogt Machine Co. bulletin on scraped surface exchangers featuring a patented scraper element to prevent fouling of inner pipe surfaces. For use as oil chillers, crystallizers, heaters. Tubes are of 6 in. diam., and for double pipe equipment are jacketed by an 8-in. tube. Scrapers are driven by heavy roller-type chain and low-speed gear motor. Full construction details are shown in drawings, illustrations of installations, and text.

28 • CRUSHERS, GRINDERS, AND SHREDDERS. A folder from Pennsylvania Crusher Co. on reversible impactors, hammermills, ring-type granulators, etc.

29 • MIXERS. Turbine-type mixers described by Mixing Equipment Co., Inc. Contains factual discussion of fluid agitation, details of construction of mixers, section on choosing the correct impeller for mixing job, selection tables for sizing of the correct units, etc. Also new line of company's mixers in sizes from 1 to 500 hp.

30 • RING PACKING. From Greene, Tweed & Co. information on ring packing for industrial applications at pressures up to 15,000 lb./sq.in. Text and illustrations cover design, operation, installation, dimensions, etc.

31 • LEAD CLADDING. A series of technical papers on lead clad steel and lead clad copper. From the Knapp Mills, Inc. Covers history and development of lead in the chemical industry, discussion of lead clad steel, lead clad copper, section of comparison of the products with lead, other sections on anodes. For engineers and design groups with corrosion problems.

32 • REMOTE PRESSURE RECORDER. An instrumentation sheet from Brown Instruments Division on remote recorder for pressures transmitted either by direct wire or telemetering. Available in 12 standard ranges from 50 to 10,000 lb./sq.in. Data sheet shows specifications, special features, operating principles, etc.

33 • SUMP PUMPS. Warren Steam Pump Co., Inc., has new models of two types of sump pumps. Bulletin describes the units, 8 sizes, 1½ to 8 in., capacities to 2000 gal./min. with heads up to 120 ft.

34 • INDUSTRIAL DRYERS. C. G. Sargent's Sons Corp. industrial dryers for chemicals, food, plastics, etc. Folder showing in pictorial form the various types of dryers in some of the industrial applications.

35 • PULSAFEEDER. For engineers with control volume pumping problems, Lapp Insulator Co., Inc., has issued a bulletin on pulsafeeder piston diaphragm pumps. Will handle most corrosive materials. Bulletin shows the operation of the pump and how, by means of an oil actuated diaphragm, liquids are forced through pumping mechanism. Completely illustrated with cutaway views, installation diagrams, capacities, sizes, rating tables, dimensions, material, etc.

36 • FLOW METER HANDBOOK. Fischer & Porter Co.'s new handbook on the selection and sizing of variable-area meters. Contains results of 15 years' research by company's engineering department. Completely describes flow meters, technical explanation of operation, comparison, models, diagrams of floats, etc. Book is mostly concerned with presentation of engineering data for this flow meter.

37 • AMPCO ALLOYS. A brief fact sheet from Ampco Metal, Inc., on alloys made by the company. Gives information on corrosion resistance and photomicrographs of alloys.

38 • NEOPRENE LIQUID LINING. For protecting equipment against abrasion and chemical corrosion, a neo-

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prene-based-liquid lining compounded by the Gates Engineering Co. For brush, dipping, or spray application to most shapes for surfaces. One gallon covers 600 sq. ft. Data on physical properties, acceleration information, etc.

39 • ***LIQUID METERS.*** Brochure of meters made by the A. O. Smith Corp. For high-speed measurement of liquids. Rotary, positive displacement type. Engineering diagrams show the construction and operation. Five different models shown. Power consumption charts. Dimension specifications and installation diagrams.

EQUIPMENT

45 • ***NYLON BEARINGS.*** A bulletin from Thompson Industries, Inc., on bearings made of nylon. The advantages, operating principles, applications and availability all covered in bulletin.

46 • ***ULTRASONIC VISCOSIMETER.*** Rich-Roth Laboratories have a continuous automatic viscosity measurement instrument using ultrasonics. Has no moving parts, operates to 650° F. at 10,000 atm. pressure. For installation permanently in pipe lines, production kettles, etc. Data sheet and advance bulletin give details on instrument operation in lube oil blending, plastics manufacture, chemical manufacture, etc.

48 • ***AERODYNE DUST COLLECTORS.*** A Swedish-developed aerodyne dust collector is introduced by the Green Fuel Economizer Co. Used in boiler plants, kilns, crushers, spray dryers, etc., wherever dust, fly ash or soot is a problem.

49 • ***EQUILIBRIUM STILL.*** Emil Greiner Co.'s new flash vaporization equilibrium still for petroleum mixtures. Modified recirculation Othmer type. Requires only 500-2000 ml. for a flash curve.

50 • ***COTTRELL PRECIPITATORS.*** Western Precipitation Corp. announces a special Cottrell precipitator for blast furnaces with features of dust collection which makes it applicable to other industries. This is the first major redesign in water-film precipitators for blast furnaces in 20 years. Shows construction details of the Cottrell unit.

51 • ***AIR LIFT DRIER.*** For dehydration P & L Welding & Machine Works, Inc., has designed an air lift drier for processing wet pulp. Uses any type heating, temperatures of 250 to 300° on the wet pulp. Dust is separated in cyclone, and while the bulletin concerns production of fish meal, design variations for other applications are possible.

52 • ***ELECTRONIC CHART CONTROLLER.*** Minneapolis-Honeywell Regulator Co. announces development of an electronically operated chart controller for industrial processes operating on time-temperature schedules.

54 • ***TURBO-DRYER.*** Large package unit of the standard turbo-dryer by the Wyssmont Co. Will be furnished completely installed for drying heat-sensitive materials. Has a variable-speed drive for rotation of the tray structure, has evaporative capacities from 50 lb. of water an hour at 100° F., to 750 lb./hr. and 350° F. for the larger units.

55 • ***DRYING AGENT CONCENTRATOR.*** Niagara Blower Co. introducing an improved model concentrator for drying agents used in humidity method of air conditioning. Drying agent (in this system) is a liquid with hygroscopic properties. New concentrator sprays liquid into an air stream over heating surfaces, which raise temperatures and evaporate water from it. Air passes through eliminator plates which remove the liquid drops, and in second stage over a cool reflux coil which condenses the absorbent vapor. In third stage, air passes through filtration cylinders each of which contains a fog nozzle. Here by building up a high humidity all absorbent liquid is condensed and the droplets caught by filters.

56 • ***MICRO ROTAMETERS.*** New micro flowmeters introduced by the Technical Equipment Co. The rotameters are for measuring small volumes of liquids and gases in laboratories and pilot plants. High and low pressure models. Have maximum flow rates of 6-105 ml./min. for water, and 90-610 ml./min. for air at 20° C. Various materials for floats and gaskets.

57 • ***FLOW METERS.*** Foxboro Co. newly designed flow meter with higher sustained accuracy and easier maintenance. Uses a pressure seal bearing. Requires no periodic lubrication maintenance. Bearings and associated parts are interchangeable as is a plastic check float immersed in a bath of mercury. Recording unit described along with other information on Foxboro meters.

59 • ***SAFETY JUGS.*** American Agile Corp. now producing polyethylene safety jugs for holding alkalis, acids, including hydrofluoric. Incorporate design in safety feature which reduces hazard of handling and splashing. Available from 1½ gal. to 3½ gal.

60 • ***PROPELLER FAN.*** Direct drive, vertical propeller fan for exhaust in laboratories, plants, etc., is new with the American Air Filter Co., Inc. Installed flush with the ceiling, totally enclosed. Ranges in size from 14 to 36 in. Cubic feet per minute delivery varies from 1,585 for a 14-in. model to 12,400 for 36-in. fan.

61 • ***PLASTIC PIPE.*** A plastic pipe primarily for water service and applications involving high vacuum by Carlon Products Corp. Light weight and flexible, requires no special tools to install. Available in sizes ranging from ¾- to 6-in. diam. Working pressures 120 lb./sq.in. at 120° F.

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ANNOUNCING A NEW ION EXCHANGE RESIN

AMBERLITE IR-112

- *AMBERLITE IR-112* is a new cation exchanger of the sulfonic type.
- *The resin* is recommended for use in municipal and domestic water softening, the conditioning of water for boiler feed, and other industrial processes.
- *Initial cost* of AMBERLITE IR-112 is low.
- *In hydrogen cycle operation,* AMBERLITE IR-112 is particularly effective, showing:
  Extremely low leakage characteristics
  Excellent regeneration efficiency
- *Economical operation* is obtained in the sodium cycle.
- *AMBERLITE IR-112,* therefore, is very efficient in split-stream dealkalization.
- *The excellent stability of AMBERLITE IR-112* assures long service life. One-year plant tests show no apparent change after treating 1,000,000 gallons of water per cubic foot; and the resin is still in service.
- *The high degree of porosity* of AMBERLITE IR-112 suggests use in unusual applications such as catalytic operations, adsorption, decolorization, and chromatological separations.

Write for literature describing AMBERLITE IR-112. And for regular reports on ion exchange developments, ask for AMBER-hi-LITES—a four-page folder, mailed bimonthly without charge.

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Only Sparkler horizontal plate design gives you the equivalent of *two* standard filters in just *one* tank.

By keeping a spare cartridge of plates ready at all times your filter need never be shut down for longer than it takes to hose down the tank and exchange the cartridge of dirty filter plates for a cartridge that is freshly dressed. This not only speeds the return of the filter to full production duty but also makes it easy for the filter operator to clean the plates whenever and wherever it is most convenient.

Besides eliminating the need for a standby filter, a spare Sparkler cartridge minimizes downtime, cuts labor costs, and makes your entire filtering operation a simple job that can be handled by just one man.

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Manufacturers of industrial filtration equipment for more than a quarter of a century

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Mundelein, Illinois

Sparkler International Corp.
Nieuwegracht 56B, Amsterdam, Holland

Sparkler Western Hemisphere Corp.
Mundelein, Ill., U.S.A.

SPARKLER FILTERS • SPARKLER FILTERS

FRENCH LICK

(*Continued from page* 33)

chemistry, Mellon Institute of Industrial Research; Brymer Williams, assistant professor, department of chemical and metallurgical engineering, University of Michigan; and Edgar L. Piret, head, department of chemical engineering, University of Minnesota. The titles of the papers are shown in the accompanying table.

The paper on the "Selection of Vacuum Pumping Systems," to be given late Monday afternoon, by L. W. Hull, Stokes Machine Co., will be a comprehensive review of the various types of vacuum-pumping equipment with emphasis on vacuum systems for the production of high vacuum. Mr. Hull will summarize the advantages and limitations of various types of pumping equipment, and will take into account capital investment, operating costs, maintenance problems, and the technical skills required by the operator.

Another paper of interest to the plant man and the engineer responsible for industrial systems, will be "Outgassing Properties of Materials Used in Vacuum Systems" by Benjamin B. Dayton, of Distillation Products Industries. Mr. Dayton will cover the outgassing characteristics of gasket materials, plastics, waxes and greases. He will present a formula for extrapolating data to typical vacuum systems relative to pumping speed and exposed surface of outgassing material.

Richard B. Lawrance, director of the applied physics department, National Research Corp., will talk on "The Characteristics of High Vacuum Vapor Pumps." Dr. Lawrance will show that for a given application, certain characteristics of a vapor pump are of primary interest. Some of these are blank off-pressure, volumetric speed as a function of inlet pressure, and maximum allowable forepressures. He will show a graphical presentation which he has evolved and which shows most-wanted data on a single sheet of log-log graph paper as a function of throughput.

In another paper, Mr. Lawrance will survey gauges used in measuring low pressures with detailed information on those gauges now thought of greatest usefulness in engineering application.

D. H. Jackson, vice-president of Croll-Reynolds, will also talk, his subject being corrosion problems in steam jets. Owing to the fact that steam in jet equipment moves at high velocity, normal corrosive action is accelerated. His address will emphasize industrial data obtained in on-the-job studies of a wide variety of corrosion-resisting materials.

Transportation

For engineers coming from New York and environs, the Baltimore & Ohio R.R. Co. has a late afternoon train which makes a direct connection in Mitchell, Ind., for the hotel. This will arrive just before noon, so those who wish to be in on the Monday morning program should plan to arrive on Sunday. Detroit and St. Louis have similar connections through the B. & O. from Chicago, the Monon R. R. has a sleeper which leaves late in the evening and arrives at the hotel the next morning. A private airport is near for those arriving in private and company planes. Bus routes also connect with the hotel from Indianapolis and Louisville. For those in the South, the Southern R. R. and the Louisville & Nashville connect at Louisville with a Monon train. Those using the N.Y.C.R.R. must change at Indianapolis to a Greyhound bus for a connection to French Lick.

The French Lick facilities are ample; 600 rooms are available, and the meeting hall with a capacity of 1200, is in one wing of the hotel. It has all the modern facilities for presentation of technical papers.

As has been pointed out by Institute officials the American plan for hotels usually is more economical than the typical European plan. At French Lick, rates on the American plan are $16 per day, and doubles will range from $14 down to $10 per day per person.

PRESSURE SYMPOSIUM BY A.S.M.E. IN FALL

Plans are now being formulated by the industrial instruments and regulators division of the American Society of Mechanical Engineers for its High Pressure Symposium scheduled during its annual meeting at Cleveland, Ohio, Sept. 8-12, 1952. A well-rounded program will be presented covering all fields relating to current operations in the pressure range from 10,000 to 150,000 lb./sq.in.

The tentative program includes papers in the following groups:

- Survey and historical
- Measurements
- Properties of materials
- Pressure vessels
- Pumps and plumbing

W. H. Howe, chief engineer, The Foxboro (Mass.) Co., will be in general charge of arrangements for the Symposium. Authors are requested to submit an abstract of their proposed papers to Mr. Howe. The deadline for a completed manuscript is May 1, 1952.

It is expected that the Symposium papers will be published in a single volume, which will then represent current knowledge on high-pressure technology.

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Complete sanitation with

SPARKLER FILTERS

The illustration above shows at a glance why Sparkler Filters are the most sanitary, most efficient filters ever designed.

Starting with the basic part of any filter — the filter element — Sparkler design makes every surface easily accessible for thorough cleaning. The few simple parts in the photo represent a complete Sparkler horizontal filter plate, with no cracks, crevices, or hard-to-reach parts that can imperil product purity by retaining objectionable material.

Once the cartridge of plates is removed from the filter, disassembly is quick and easy. Just loosen the tie-rods and the plates come apart in 1 - 2 - 3 order. Lift the paper off, remove the perforated metal wafer, then remove the supporting plates. One man does the entire job in a matter of minutes.

Inside the tank, too, complete sanitation has been provided for. All surfaces are smooth, and all joints are rounded off for accessibility and thorough cleaning.

When you need absolute product purity, you are safest with Sparkler.

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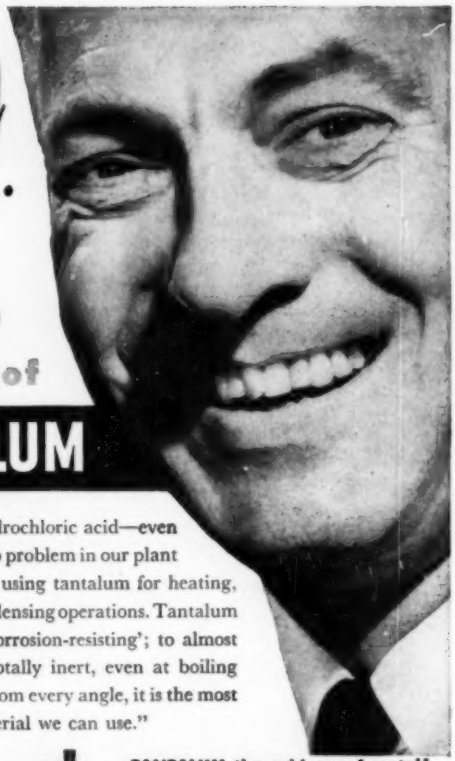
"Boiling HNO_3!... just like water with Acid-Proof TANTALUM



"Nitric acid, hydrochloric acid—even aqua regia are no problem in our plant since we started using tantalum for heating, cooling, and condensing operations. Tantalum is not merely 'corrosion-resisting'; to almost all acids, it is totally inert, even at boiling temperatures. From every angle, it is the most economical material we can use."

TANTALUM the acid-proof metal! Tantalum's speed in heat transfer, freedom from thermal shock, and acid-proof properties add up to equipment that increases production, saves time and space, saves maintenance, saves shutdown time, and eliminates product contamination due to corroded equipment.

Use TANTALUM With Economy for most acid solutions, corrosive gases or vapors; not with HF, alkalis, substances containing free SO_3.

Tantalum Steam Coil. Additional heating capacity obtained by building coil on large steel flange protected by tantalum tube sheet, eliminating risers. Connections are at bottom.

Write for the Fansteel booklet, "Tantalum Acid-Proof Chemical Equipment", and consult Fansteel for designs and recommendations.

TANTALUM the most nearly perfect material of construction

Acid-Proof TANTALUM

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Fansteel Metallurgical Corporation NORTH CHICAGO, ILLINOIS, U.S.A.

NEWS

(*Continued from page 55*)

GRANTS IN AID FOR SCIENCE, EDUCATION

Grants in aid totaling $875,000 were made by Research Corporation in its 1951 fiscal year, it was announced recently by Joseph W. Barker, president of the foundation. The sum was distributed in the form of 288 grants to educational and scientific institutions.

In the annual report covering the foundation's 39th year of operation, Dr. Barker notes that Research Corporation's fields of disbursement are being strongly influenced by the indirect effects of government-sponsored research on the smaller educational institutions. In the face of current competition, the smaller colleges find it harder and harder to keep together the staffs needed for science teaching and independent research projects, according to Dr. Barker. To support research in such colleges, Research Corporation last year distributed through its Cottrell grants program more than $350,000 to the smaller colleges of liberal arts and sciences.

Since its founding in 1912 by Frederick Gardner Cottrell, chemist, educator and philanthropist, the foundation has distributed grants amounting to nearly $7,000,000 primarily in the fields of physics, chemistry, engineering, etc.

PERSONNEL NEEDED FOR POSITIONS WITH A.E.C.

The Atomic Energy Commission is in need of persons with chemical engineering training and with 5 to 15 years' experience in large-scale production plant operations, including production supervision, cost analysis and control, and production planning and scheduling. The salary range of several open positions is $7040-$9360 a year. These positions will be located in Washington, D. C., and in various regional offices in the U. S.

Those interested in these positions should send full background information to George M. Gableman, U. S. Atomic Energy Commission, Wash. 25, D. C.

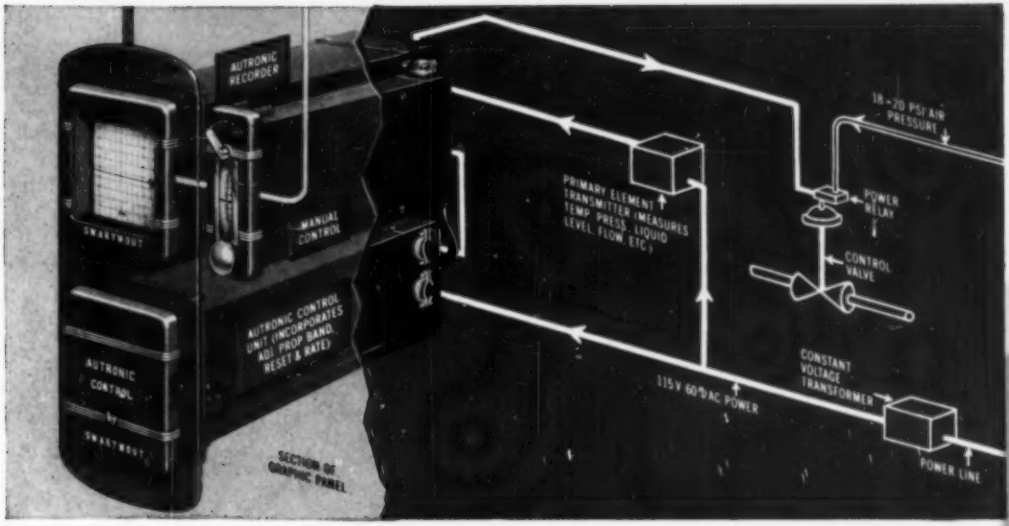
INSTRUMENT COURSE OF FISCHER & PORTER

The Fischer & Porter Co. announces that its next instrumentation course will be held at the Hatboro (Pa.) plant, May 12-16, 1952. This course will cover manufacture, calibration, installation, operation and maintenance of primary and secondary process control instruments.

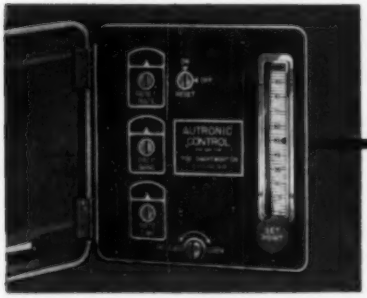
Further details can be obtained by writing to the Fischer & Porter Co., East County Line Road, Hatboro, Pa.

(*More News on page 66*)

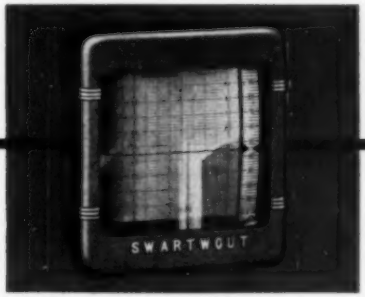
Miniature all-electronic system for instantaneous measurement and control of process variables...



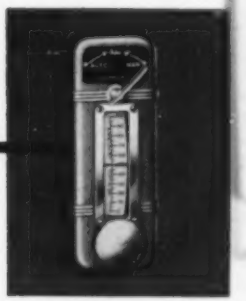
1 Regardless how fast a pneumatic or electro-mechanical system may function, it cannot compare with the *instantaneous, all-electronic* response of the Swartwout Autronic Control System. Here's why. Since transmission of information throughout the system is by *electrical means only*, there is no mechanical motion . . . no slide wires, boosters or motors to initiate control action . . . no control air lines from primary element or to final element. Hence the Autronic Control System *spans distance between primary and final elements without interval* —for closer, more accurate control.



2 **AUTRONIC CONTROLLER**, heart of the system, has no moving parts. Proportion, reset and rate-action adjustments; with or without built-in set-point adjustment. Extremely compact, plug-in type units are interchangeable; can be used direct or reverse-acting.



3 **AUTRONIC RECORDER** operates without slide wires or other contacting mechanisms. Electronically controlled pen gives true linear trace. Unit holds 1-month supply of standard 3-inch linear or square root chart paper. Set-point adjustment optional with Autronic Recorder.



4 **AUTRONIC MANUAL CONTROL** makes bumpless changeovers simple. No gauges to synchronize, no readings to remember because indicator shows *difference* between actual and desired output.

Swartwout *Autronic* **CONTROL SYSTEM**

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CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before May 15, 1952, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st., New York 17, N. Y.

APPLICANTS FOR ACTIVE MEMBERSHIP

Acker, David E., *Lexington, Mass.*
Babcock, J. A., *Wilmington, Del.*
Barber, J. C., *Florence, Ala.*
Bell, George R., *Manville, N. J.*
Broughton, Donald B., *Chicago, Ill.*
Chatfield, J. N., *Baytown, Tex.*
Colburn, L. E., *Mission, Kan.*
Draper, Richard J., *Flushing, N. Y.*
Eakins, William J., *Oradell, N. J.*
Fisher, Charles Harold, *Somerville, N. J.*
Govan, William J., *Beverly Hills, Calif.*
Gressingh, L. E., *Painesville, Ohio*
Haaland, Harold H., *North Hollywood, Calif.*
Hale, David C., *Trenton, Mich.*
Hand, Robert S., *Wilmington, Del.*
Harty, W. M., *Richland, Wash.*
Hilliker, Harry H., *St. Louis, Mo.*
Humphrey, William J., *Pittsburgh, Pa.*
Keller, William R., *Danville, Ill.*
Licht, William, Jr., *Cincinnati, Ohio*
Loch, Luther D., *Columbus, Ohio*
Martin, William J., *Oak Ridge, Tenn.*
McCurdy, J. Lloyd, *New London, Conn.*
McFarlane, R. W., *Louisville, Ky.*
Morley, F. Robert, *Westfield, N. J.*
Nash, John F., *Benson, Ariz.*
Newman, Philip E., *Paris, France*
Nimmo, Robert H., *Oak Ridge, Tenn.*
Oden, E. Clarence, *Lake Charles, La.*
Persell, Ralph M., *New Orleans, La.*
Pietzsch, K. F., *Pittsburgh, Pa.*
Pownall, John R., *Long Beach, Calif.*
Price, John M., *Baltimore, Md.*
Richert, A. B., *Tulsa, Okla.*
Ryant, Charles J., Jr., *Chicago, Ill.*
Schreiner, Warren C., *New York, N. Y.*
Seveland, Carl B., *Chicago, Ill.*
Simons, Howard P., *Morgantown, W. Va.*
Smith, Sidney C., *Wilmington, Del.*
Tenthoff, Edward H., *Beaver, Pa.*
Tomlinson, Walter J., Jr., *Fort Lee, N. J.*
Wall, Henry H., Jr., *Baton Rouge, La.*
Wallace, Alexander E., *Neenah, Wis.*

APPLICANTS FOR ASSOCIATE MEMBERSHIP

Anderton, Arthur, *Deep River, Ont., Canada*
Palermo, Joseph A., *Rochester, N. Y.*
Poss, Fred J., *LaGrange Park, Ill.*

APPLICANTS FOR JUNIOR MEMBERSHIP

Akoury, James N., *Long Beach, Calif.*
Anslow, James R., *Texas City, Tex.*
Apotheker, Jerry, *Chicago, Ill.*
Aslakson, R. Corbin, *Midland, Mich.*
Bahor, Ernest M., *St. Albans, W. Va.*
Baldini, Reginald A., *Sunbury, Pa.*
Blackburn, Robert J., *Wilmington, Del.*
Boyle, Robert J., *Union, N. J.*
Boys, Roger L., *Kingsport, Tenn.*
Buchanan, Joel R., *Oak Ridge, Tenn.*
Bumble, Paul, *Brooklyn, N. Y.*
Burke, Robert Francis, *E. Orange, N. J.*
Campbell, David V., *Orange, Tex.*
Carlson, Edgar, *Tallant, Okla.*
Clancey, James T., *Pittsburgh, Pa.*
Clark, Edward L., *Buffalo, N. Y.*
Cobb, E. R., *Port Neches, Tex.*
Cochrane, John D., III, *Wilmington, Del.*
Constan, Gus L., *Midland, Mich.*
Cruikshank, John D., *Barberton, Ohio*
Cuthbert, H. Jane, *Rocky River, Ohio*
Cyphers, A. D., Jr., *Charleston, W. Va.*
Dale, Kenneth Howard, *Wood River, Ill.*
Davis, Bruce A., *Port Neches, Tex.*
Davis, Murray L., *Terre Haute, Ind.*
Deindoerfer, Fred H., *Rahway, N. J.*
Derrig, Donald J., *Watkins Glen, N. Y.*
DiBenedetto, Vincenzo, *Newark, N. J.*
Dickinson, Dean, *Dayton, Ohio*
Dobucki, Leonard J., *Frederick, Md.*
Doperalski, Eugene J., *Midland, Mich.*
Dunlap, Wallace P., Jr., *Grosse Ile, Mich.*
Faltings, John P., *Glendale, N. Y.*
Fecht, Edward Theodore, *Astoria, N. Y.*
Finch, George N., *Albany, N. Y.*
Fitzgibbon, John T., *Newark, N. J.*
Forkos, Jerome F., *Long Island City, N. Y.*
Fox, Charles H., *Crystal Lake, Ill.*
Friedman, Robert, *Cleveland, Ohio*
Gately, Philip M., *Scarsdale, N. Y.*
Glassett, Joseph M., *Salt Lake City, Utah*
Greiner, Eleanor A., *Marcus Hook, Pa.*
Gross, Lawrence, *Indianapolis, Ind.*
Grossman, Elihu D., *Phila., Pa.*
Harrison, Charles W., *Cushing, Okla.*
Harrison, Jonas P., *Army Chemical Center, Md.*
Heney, Lysle J., Jr., *Dunellen, N. J.*
Hirsch, Albert E., *Charleston, W. Va.*
Hoag, E. H., *Fullerton, Calif.*
Holbrook, C. Ray, Jr., *College Station, Tex.*
Hogue, Harry, *Redondo Beach, Calif.*
Horn, Alvin W., *Midland, Mich.*
Horner, Harold R., Jr., *Port Arthur, Tex.*
Hough, Robert R., *Wilmington, Del.*
Huebner, Frederic E., *Wilmington, Del.*
Hughes, J. Wilton, *Baltimore, Md.*
Husain, A., *Hyderabad-Dn, India*
Huskinson, John C., *Wilmington, Del.*
Jackson, Donny R., *Brady, Tex.*
Jackson, Hedley V., *Port Neches, Tex.*

(*Continued on page 60*)

High Temperatures Without Pressure

Merrill Process System of circulating hot oil has many advantages

Product temperatures up to 550°F. Far beyond the range of steam at corresponding pressure. Merrill Process pressures negligible as system is vented to the atmosphere. No danger from direct fire. No offensive odor. Thermostatic control keeps heating oil within a few degrees, high enough to do job without overheating batch.

High Temperature Resinous Products

Versatile, Dependable, and Safe

Penstock Asphalt Coating

Versatile—may be used on product equipment that cannot stand pressure such as glass-lined vessels.

Dependable—just smooth, quiet, delivery of heat. Any quantity, any temperature. 35 years of sound, practical experience guarantees that.

Safe—all the time. Steel pumps, steel valves, steel fittings and accessories, extra heavy at that. Insurance companies like these features.

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Complete line of Jacketed Fittings too: Bulletin 152

Parks-Cramer Company

ENGINEERING, MANUFACTURING, AND INSTALLING

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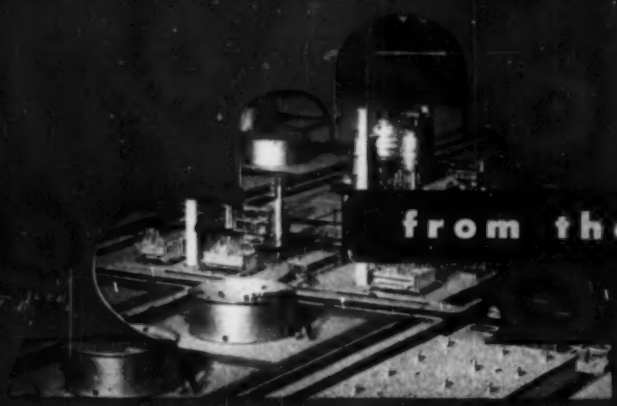
new products



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These products are now being made in petroleum refineries.

Foster Wheeler's integrated engineering and construction organization has served both the petroleum and chemical industries for over 30 years in the design and construction of process units and complete refineries and chemical plants.

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FW

CORROSION-PROOFED BY PENNSALT

TOWER LINING: Brick laid in Penchlor Cement over rubber interliner.
METAL SURFACES: Guarded by Pennpaint coating.
SUPPORTS & FLOORS: Asplit Cement used as mortar, over Penncoat interliner.

For 13,200 hours . . . this room has handled H_2SO_4 saturated with chlorine

This room is a good example of Pennsalt anti-corrosion know-how. It is *our own room*, protected by Pennsalt products, at our Wyandotte, Michigan, plant.

Notice the "new" look about this room—despite the fact that for a year and a half it has been continuously handling highly corrosive sulfuric acid saturated with chlorine.

This is the kind of results you can expect when you take your corrosion problems to Pennsalt . . . a company that not only makes anti-corrosion products, but also lives with the same type of corrosion problems you yourself do.

Thorough-going research, plus many years of sales-engineering experience, combine to offer you 15 different corrosion-resistant cements, as well as paints, to meet your needs. From the floor to the top of your smokestack, we can offer you qualified counsel and job-proved products to lick the problem. Write: Corrosion Engineering Products Department, Pennsylvania Salt Manufacturing Co., Phila. 7, Pa.

PENNSALT CHEMICALS
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CANDIDATES

(*Continued from page 58*)

Johnston, Gerald D., *Greensburg, Ky.*
Jones, Virgil Wayne, *Borger, Tex.*
Jonke, Albert A., *Elmhurst, Ill.*
Kaplan, Milton, *Harvey, Ill.*
Kapp, L. F., *Chicago Heights, Ill.*
Karwan, Steven J., *Linden, N. J.*
Kaswell, Wm. E., *Barberton, Ohio*
Keller, David P., *Trenton, N. J.*
Kessler, Arthur J., *Wilmington, Del.*
Kiyonaga, Kazuo, *Oahu, Hawaii*
Klopp, Ralph M., *St. Albans, W. Va.*
Kraus, Leonard H., *Brooklyn, N. Y.*
Lamb, Thomas N., *Borger, Tex.*
Leisy, Arthur E., *St. Louis, Mo.*
Lieberman, Ephraim, *Oak Ridge, Tenn.*
Lindahl, Donald R., *Library, Pa.*
Lindstrom, Carl A., Jr., *Melrose, Mass.*
Maiuri, Frank P., *Washington, D. C.*
Marriner, Donald E., *Maplewood, Mo.*
Maurer, John Frederick, *Newport, Del.*
Mayer, Paul M., *Highland Park, Ill.*
McAdoo, John D., Jr., *E. Orange, N. J.*
McCarthy, Thomas M., *Cambridge, Mass.*
McDermott, Daniel E., *Richmond, Va.*
McGoff, Miles J., *Warrendale, Pa.*
McNeer, William S., *Charleston, W. Va.*
Mogaard, Thomas E., *Chicago, Ill.*
Mullendore, John A., *St. Louis, Mo.*
Murch, Robert M., *Midland, Mich.*
Myron, Thomas L., *Pittsburgh, Pa.*
O'Brien, Raimund F., Jr., *Lawrence, Kan.*
Osborne, William F., Jr., *Orange, Tex.*
Oster, Bernd, *Providence, R. I.*
Pasteelnick, Louis, *Newark, N. J.*
Pettrillo, John M., *Foxboro, Mass.*
Pittman, E. Henry, Jr., *Seneca, S. C.*
Ponisi, Harry P., *Parlin, N. J.*
Popovich, John D., *Gainesville, Fla.*
Post, Daniel, *Hopewell, Va.*
Prehn, W. Lawrence, Jr., *Dallas, Tex.*
Pritsker, Theodore P., *Philadelphia, Pa.*
Purdom, John L., *Charleston, W. Va.*
Rea, Homer E., Jr., *Berkeley, Calif.*
Reeder, Clyde, Jr., *Wilmington, Del.*
Rein, Harold F., Jr., *Detroit, Mich.*
Rion, Jimmy, *Hendersonville, N. C.*
Rosenberg, Philip, *Brooklyn, N. Y.*
Samuels, Jack E., *Cuyahoga Falls, Ohio*
Schultz, Thomas Q., *Huntington Park, Calif.*
Setzler, William E., Jr., *Seaford, N. Y.*
Shirk, Elmer E., Jr., *Beaver, Pa.*
Slonaker, Robert E., Jr., *Lewisburg, Pa.*
Streib, William C., *Somerville, N. J.*
Sunnygard, John R., *Monsanto, Ill.*
Svoboda, J. J., *Chicago, Ill.*
Szabol, John M., *Brooklyn, N. Y.*
Tallmadge, John A., Jr., *Pittsburgh, Pa.*
Talmage, William P., *Buffalo, N. Y.*
Tarkington, Terry W., *Malden, W. Va.*
Taylor, William C., Jr., *Hammond, Ind.*
Vasil, Thomas, *Lansing, Ill.*
Waddell, Russell B., Jr., *Louisville, Ky.*
Wadler, Ralph Milton, *Detroit, Mich.*
Weiner, Louis H., *New York, N. Y.*
Wetherell, Charles J., *Louisville, Ky.*
Williams, Richard P., *Omaha, Neb.*
Wolf, Herbert Otto, *Wilmington, Del.*
Yu, Tsi Shan, *Atlanta, Ga.*
Yuan, Shao-Yuen, *Secane, Pa.*
Zabriskie, Kenneth H., Jr., *Wilmington, Del.*
Zachow, Herbert H., *Springfield, Pa.*

Secretary's Report

S. L. TYLER

THE Executive Committee of the Institute met at the Atlanta-Biltmore Hotel in Atlanta, Ga., March 16. The first items on the agenda were the approval of the previous Minutes, receiving of the Treasurer's Report and approval of bills. All those candidates for membership whose names appeared in the February issue of "C.E.P." were elected to the grades of membership as indicated. There were also 88 Student Members elected which brings the total of Student Memberships to date to 1,712.

Invitation had been received for the Institute to appoint representatives to attend the annual meeting of the American Academy of Political and Social Science. It was voted to appoint A. P. Colburn and M. C. Molstad.

J. M. Woods was appointed counselor of the student chapter at the University of Rhode Island to succeed H. E. Graves.

The following were placed on the Suspense List because of their having entered the Armed Forces: John A. Banik, Glenn M. Blouin, H. P. Donohue, D. P. Rice, H. R. Sanders and Kurt Wohl.

M. Souders, B. F. Dodge and W. H. McAdams were appointed as Institute representatives on Subcommittee 5 on Heat and Thermodynamics of Sectional Committee on Letter Symbols and Abbreviations for Science and Engineering of the A.S.A.

Resignation was received from C. G. Kirkbride as the Institute representative on the Executive Committee of E.C.P.D. He had served for several years. W. N. Jones was appointed his successor.

The Council met at the Atlanta-Biltmore Hotel, Atlanta, March 16. The Revised By-Laws were approved and authorized for publication in Year Book.

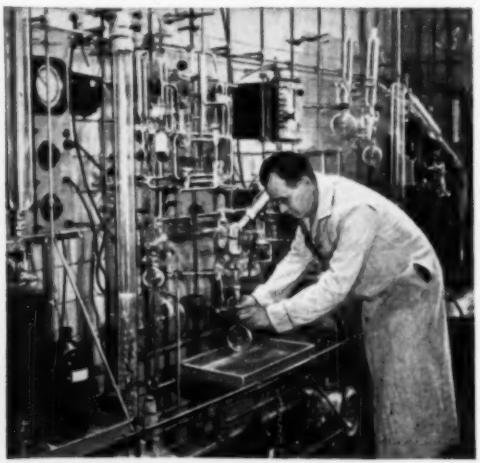
An invitation to hold a national meeting of the Institute in Springfield, Mass., was received from the Western Massachusetts Section and accepted with the date set for May, 1954. An invitation was accepted to hold a meeting in New York, in December, 1954.

C. E. Ford as chairman of the Local Sections Committee attended the meeting; the problems of his committee were discussed and plans for activities for the balance of this year were approved.

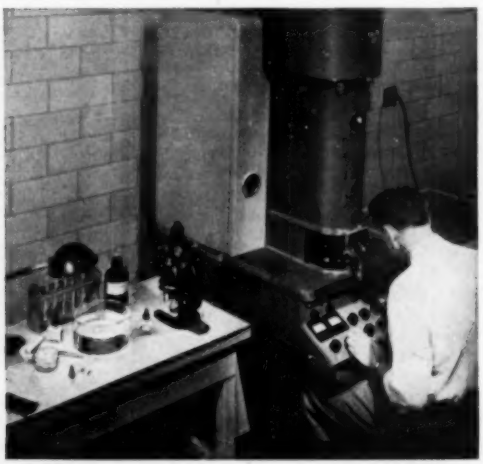
An application was received for the granting of local section status to the Southeastern Association of Chemical Engineers and this was approved with the name of the section tentatively approved as the Southeastern Section.

These Great Laboratory

PETROCHEMICALS offer independent inventors great opportunity for exploration and reward. Such synthetics as Nylon, Vinylite, Neolite are already indispensable to our expanding economy—and new ideas in this area are at a premium today.



UNDER THE SINCLAIR PLAN, chemistry laboratories like these are open for the first time to independent inventors.



ELECTRON MICROSCOPE, capable of magnifying 100,000 times, is typical of the expensive equipment now available.

Facilities Are Open to You

Many inventive people have responded to the Sinclair Plan's offer of laboratory facilities — to others who wish to do so, a suggestion: There is promise and profit in oil-based synthetics.

EIGHT months ago, Sinclair turned over a part of its great laboratories at Harvey, Illinois, to independent inventors who had promising ideas in the field of petroleum products but who did not have the facilities needed to develop or prove out their ideas.

To date nearly 5,000 people have submitted ideas to the laboratories, and the Plan is recognized as a valuable service to independent inventors. As a result we have made the Sinclair Plan part and parcel of the long-range operation of our company.

There may be inventive people interested in this Plan but wondering what sort of ideas or what areas would be profitable to explore. To those people we suggest the field of petrochemicals. Such things as plastics, synthetics, substitutes and new materials as yet undeveloped—made from petroleum—offer great opportunities for invention and reward.

If you have an idea of this sort—or in the general area of petroleum products or applications—you are invited to submit it to the Sinclair Research Laboratories. In your own interest, each idea must first be protected by a patent application or a patent.

The inventor's idea remains his own property

If the laboratories select your idea, they will make a very simple arrangement with you: In return for the laboratories' work, Sinclair will receive the privilege of using the idea for its own companies, free from royalties.

This agreement in no way hinders the inventor from selling his idea to any of the hundreds of other oil companies for whatever he can get. Sinclair has no control over the inventor's sale of his idea to others, and has no participation in any of the inventor's profits.

HOW TO PARTICIPATE: Instructions are contained in an Inventor's Booklet available on request. Write to: W. M. Flowers, Executive Vice-President, Sinclair Research Laboratories, Inc., 600 Fifth Avenue, New York 20, N. Y.

IMPORTANT: *Please do not send in any ideas until you have sent for and received the instructions.*

SINCLAIR RESEARCH LABORATORIES—nine buildings containing the most modern testing equipment known—have contributed many of today's most important developments in petroleum. Under the Sinclair Plan, the available capacity of these great laboratories is being turned over to work on the promising ideas of independent inventors everywhere.

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Replacement of the steam drive on our boiler feed conveyor with Speed-Trol, reduced power costs 75%, saved 80% floor space, and the only maintenance in 2 years continuous operation has been normal lubrication. We recommend Speed-Trols for dependability, infinite speed control, accurate speed regulation under varying loads, compactness and low maintenance, reports Roscoe Hubbard, Chief Electrician, W. E. Belcher Lumber Company.

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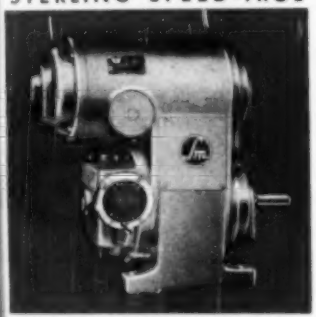

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MARGINAL NOTES

News of Books of Interest to Chemical Engineers

A Sound Basis for a Unique Tool

Dimensional Analysis and Theory of Models. Henry L. Langhaar. John Wiley & Sons, Inc., New York. (1951) 166 pp. $4.00.

Reviewed by J. H. Rushton, Director, Department of Chemical Engineering, Illinois Institute of Technology, Chicago, Ill.

DIMENSIONAL analysis has been receiving much popular attention in recent years as evidenced by several new books recently published on the subject. This book is an excellent and concise treatment of the philosophy and mathematics of dimensional analysis. His use of determinant mathematics as a systematic means of calculating dimensionless products is particularly useful. The book is recommended for anyone interested in the phenomena of mass transfer, heat transfer, and for any processing wherein fluid mechanics plays a part.

Langhaar defines dimensional analysis as a "method by which we deduce information about a phenomenon from the single premise that the phenomenon can be described by a dimensionally correct equation among certain variables. The generality of the method is both its strength and its weakness. With little effort, a partial solution to nearly any problem is obtained. On the other hand, a complete solution is not obtained, nor is the inner mechanism of a phenomenon revealed, by dimensional reasoning alone."

After showing that the analysis often requires a philosophic insight into the natural phenomena involved, the author reviews the mathematics involved in the concept. He demonstrates the advantages of a numerical procedure using determinants to obtain complete sets of dimensional products. This is followed by a discussion of the theories and techniques of model testing. Examples are given in the fields of stress and strain, heat flow, electromagnetic theories, and fluid mechanics.

There are few illustrations of model testing of direct use to chemical engineers except those in heat transfer. However, inasmuch as chemical engineers are becoming increasingly aware of the utility of dimensional analysis in pilot-plant and scale-up considerations, it is stimulating to consider the progress made in model study by other fields of engineering, and to visualize analogies that may be applicable to chemical processing. This book offers a sound basis for a fundamental understanding of the unique tool called "dimensional analysis."

Facts Really Classified

Statistical Methods for Chemists. W. J. Youden. John Wiley & Sons, Inc., New York. (1951) 126 pp. $3.00.

Reviewed by Elmer P. Foster, Atomic Energy Division, Du Pont Co., Wilmington, Del.

W. J. YOUDEN, statistician with the National Bureau of Standards, has written a "primer of statistics for chemists." It is a good primer for both the chemist and engineer in the experimental laboratory. The arguments for experiments planned for efficient interpretation are excellent. They should certainly be read by all engineers undertaking a program of laboratory or pilot plant study.

The treatment of "precision and accuracy" and the use of small sets of data are good. Each of the statistical tests described is explained in as much detail as can be expected in a small book covering so extensive a field. Some of the test explanations are the simplest and best this reviewer has seen.

The failure of the author to mention quality control charts is hard to accept. This tool has been most valuable financially. It is the first tool the chemist or engineer should learn.

The reviewer also senses a void when he reads such statements as, "Statistical texts give formulas for second- and higher-degree equations" in reference to regression curve calculations. What books? Where should the reader look?

Certainly most readers will want to explore the statistical tool further after this introduction to the field.

Books Received

Data Book for Civil Engineers. Vol. 1, Design; Vol. 2, Specifications and Costs. Elwyn E. Seelye. John Wiley & Sons, Inc., New York, N. Y. (1952.) Vol. 1, Seven Sections, $10.00. Vol. 2, 506 pp., $13.00. Page size 11½ by 9¼. Third volume in preparation on Field Practice.

A Study of Antimetabolites. D. W. Woolley. John Wiley & Sons, Inc., New York. Chapman & Hall, Ltd., London. (1952) 269 pp. $5.00.

Fluorine and Its Compounds. R. N. Haszeldine and A. G. Sharpe. Methuen & Co., Ltd.; John Wiley & Sons, Inc., New York. (1951) 153 pp. $1.75.

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"Johns-Manville Quality Products" is a 40-page manual describing more than fifty Johns-Manville products that are helping process industry men save power, reduce upkeep and cut fuel costs. Its useful data covers many types of Johns-Manville Insulations for tanks and vessels, piping, boiler walls, etc. . . . also J-M refractories, packings, gaskets, friction materials, Transite asbestos-cement pipe and Transite* Insulated rot-proof roofs. A manual you will refer to often for helpful information!

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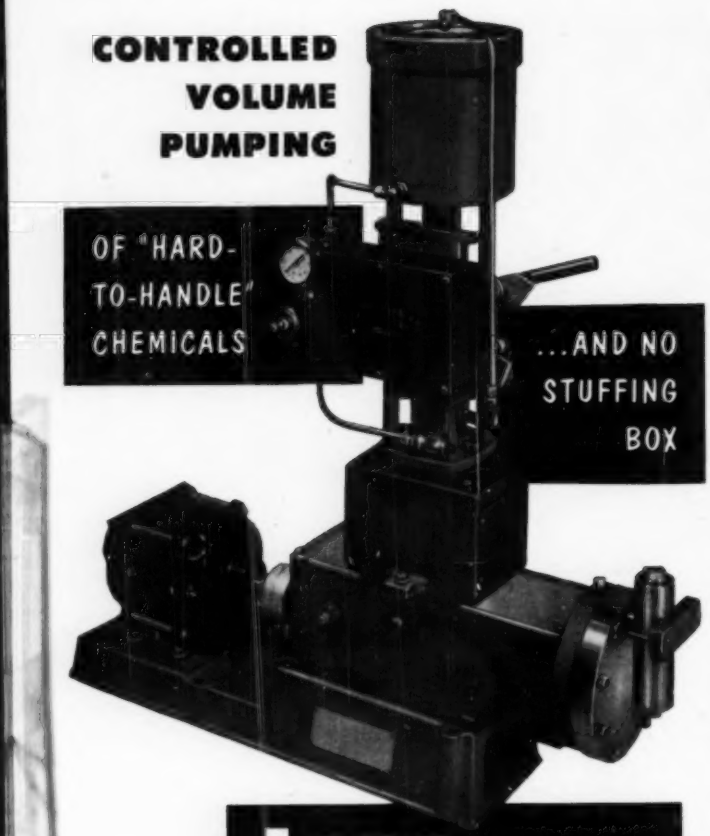

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NEWS

(*Continued from page 56*)

W. I. BURT HEADS M.C.A. COMMITTEE

At the conclusion of the two-day Air Pollution Abatement Conference sponsored by Manufacturing Chemists' Association in February it was announced that William I. Burt, vice-president in charge of manufacturing, B. F. Goodrich Chemical Company of Cleveland, Ohio, and President of the A.I.Ch.E., was elected chairman of MCA's Air Pollution Abatement Committee. He succeeds J. M. Gillet, assistant to the president of Victor Chemical Works.

EMPLOYEE THRIFT PLAN OF ATLANTIC REFINING

The Atlantic Refining Co. announces an agreement with the Atlantic Independent Union which will make thrift and savings benefits available to employees represented by the union. The company stated that similar benefits would be extended to employees in the United States not represented by any union. Employees may contribute from one to five per cent of their base pay and Atlantic will match them 50 cents on the dollar.

FULBRIGHT COMPETITION FOR AWARDS ANNOUNCED

A poster announcement of the 1953-54 competition for awards under the Fulbright Act for university lecturing and postdoctoral research in East Asia and the Pacific has been circulated by the Committee on International Exchange of Persons of the Conference Board of Associated Research Councils.

The poster refers to Fulbright awards for university lecturing and advance research only. Later the Institute of International Education will announce the Fulbright graduate program for 1953-54. Graduate students desiring to enroll for courses abroad or to pursue a directed program of studies at the predoctoral level should apply to their local Fulbright program advisers or directly to the Institute of International Education in New York City, before October, 1952.

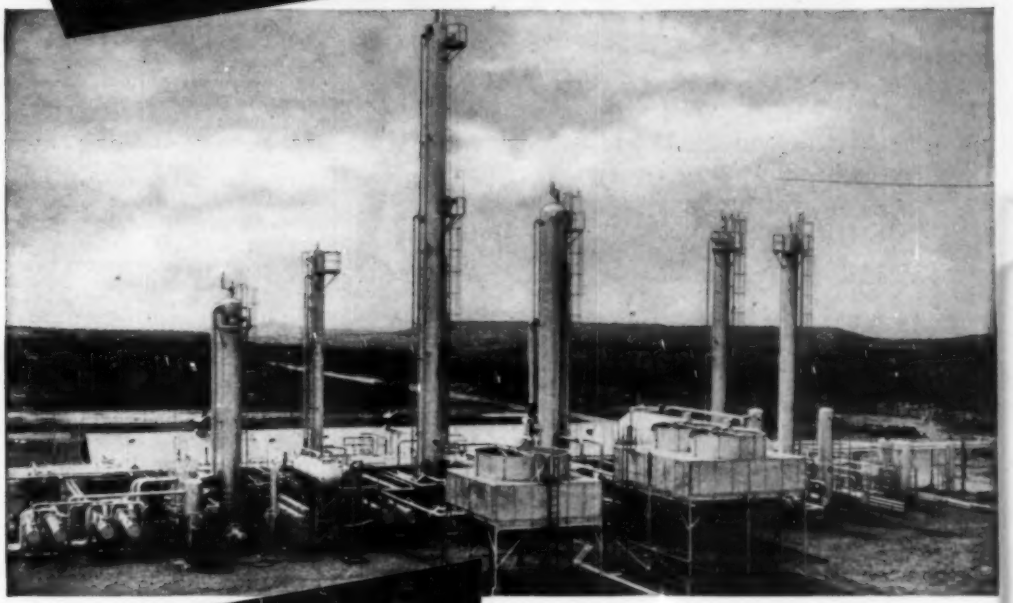
INDIANA ENGINEERING COUNCIL EXPOSITION

Several thousand college and high school students will visit Purdue University in Lafayette, Ind., May 2-4, to attend the Indiana Eng. Exposition.

This Exposition, which will be held in the Purdue University Armory, is sponsored by the Council to show students the opportunities in engineering.

The Engineering Manpower Commission of E.J.C. will also participate.

Reduce Fouling in your plant



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STORY...

...about the punch-drunk fighter who staggered back to his corner at the end of each round and looked pleadingly at his handler, as he heard the familiar words, "Good work, boy, he hasn't laid a glove on you." Wiping the blood from his mouth, he whispered in all earnestness, "For gosh sakes, Joe! Keep your eye on the referee. Someone in there is giving me a hell of a beating."

Seeing the article "Don't Fear Threading of Stainless" made me feel that its author, was similar to the handler of the punch-drunk fighter, and so I dropped in to have a chat. I told him that I had heard so many complaints about threading of stainless steel that I felt pretty confident the job must be a tough one, and I wanted to know where he got off saying that we didn't have to fear the threading of stainless.

Well, the author did two things. First, he explained to me that for people who thread stainless regularly and for people who really take the time to know what they're doing, there is no real problem; secondly, he took me out into the shop to demonstrate what he had been talking about, and what he had written about in his article. If I hadn't seen it with my own eyes I wouldn't believe it. The Stainless Engineering and Machine Works Division of Cooper Alloy threads and taps stainless steel at production rates which are staggering. And the inspection division backs up their claim of uniform high quality.

For an inside picture of how it is done write for your free copy of "Don't Fear Threading of Stainless."

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LOCAL SECTION

BOSTON

Symposium—Economic Aspects of Chemical Engineering Projects

WILLIAM T. NICHOLS, vice-president of A.I.Ch.E., and director of the general engineering department of Monsanto Chemical Co., will be the key speaker at the second annual technical symposium of this Section on April 16. The meeting will be held at the University Club.

Among the subjects scheduled for the afternoon meeting are the language of cost estimates and economic analyses, a review of preconstruction capital cost estimating methods, estimating factory operating costs and total sales costs, risks encountered in profit estimates, and over-all economic analysis of chemical engineering projects.

A. W. Fisher of Arthur D. Little, Inc., will conduct a panel discussion following the afternoon presentations. Members of the panel are John Cooper, Massachusetts Investors Trust; Alexander T. Daignault, Dewey & Almy Chemical Co.; Karl Finsterbusch, Stone & Webster Engineering Corp.; Charles H. Sommer, Monsanto Chemical Co.

The papers which will be presented are as follows:

2:00 P.M.—*The Language of Cost Estimates and Economic Analyses*—R. D. Beattie, Godfrey L. Cabot, Inc., and J. Edward Vivian, Mass. Inst. of Technology.

2:20 P.M.—*A Critical Review of Preconstruction Capital Cost Estimating Methods*—Randolph Antonsen, Godfrey L. Cabot, Inc., and D. N. Peaslee, Stone & Webster Eng. Corp.

2:40 P.M.—*Estimating Factory Manufacturing Cost and Total Cost of Sales*—H. R. Marty, Dewey & Almy Chemical Co., and C. J. Matthew, Arthur D. Little, Inc.

3:00 P.M.—*Risks Encountered in Profit Estimates*—E. D. Compton, Monsanto Chemical Co., and L. G. Gilbert, Godfrey L. Cabot, Inc.

3:20 P.M.—*Overall Economic Analysis of Chemical Engineering Projects*—C. A. Stokes, Godfrey L. Cabot, Inc., and Gordon Kiddoo, National Research Corp.

4:00 P.M.—Panel Discussion:
John Cooper, Industry Specialist, Mass. Invest. Trust.
Alexander T. Daignault, Treasurer, Dewey & Almy Chemical Co.
Karl Finsterbusch, Vice-Pres., Stone & Webster Eng. Corp.
Charles H. Sommer, Jr., General Manager, Merrimac Div., Monsanto Chemical Co.
A. W. Fisher, Jr., Arthur D. Little, Inc., moderator.

Dinner Speaker—W. T. Nichols.
Program Committee Chairman—Arthur Pratt.

Reported by L. F. Loutrel, Jr.

PITTSBURGH

A panel discussion on "Obtaining a Valid Impression about a Job from an Employment Interview" featured the annual Student Night sponsored by this Section. Invited guests to the meeting, held March 5 in the Social Room of Stephen Foster Memorial on the University of Pittsburgh campus, were senior students from Pittsburgh district universities and colleges. George E. Jones, Jr., of the chemical engineering department, University of Pittsburgh, presided over the sessions.

Included in the panel were representatives from the following industrial and research organizations:

National Advisory Committee for Aeronautics, Lewis Flight Propulsion Laboratory, Cleveland, Ohio
Sylvania Electrical Products, Emporium, Pa.
Westinghouse Electric Corp., Pittsburgh, Pa.
Carbide and Carbon Chemicals Co., Union Carbide & Carbon Corp., South Charleston, W. Va.

Such primarily nonchemical activities were deliberately selected for discussion, in order to emphasize the diversity of skills expected of the young chemical engineer.

Reported by Hugh L. Kellner

MIDLAND

The fourth meeting of this Section (in formation) was held at the Dow Auditorium with 84 in attendance.

A. W. Davison of Owens-Corning Fiberglas Corp., spoke about Fiberglas. He gave a brief history of the art of glass making, describing the physical and chemical properties of glass and glass fibers and telling about the three methods of making the fibers. Many samples of the end use of the fibers were exhibited in the field of heat and sound insulation.

John Park, director of the Ashton (R.I.) laboratory of the same company, described the various end uses of Fiberglas in the textile field.

Before the main talk, Herman Yoder, a former Midland resident, gave a short description of the "Dow Pump Testing Stand." Mr. Yoder is now with Dow at Ludington in charge of the engineering section of the plant there.

Reported by Raymond Duddleston

SOUTHERN CALIFORNIA

The March 18 meeting was held at the Rio Hondo Country Club with W. H. Nims, assistant director, Ford Foundation, as featured speaker. He described the various areas in which the Ford Foundation works with its assets of $500,000,000 dedicated to the advancement of human welfare.

Reported by G. S. Peterson

(*More Local Section News on p. 70*)

CHECK YOUR *Sulfur Recovery*

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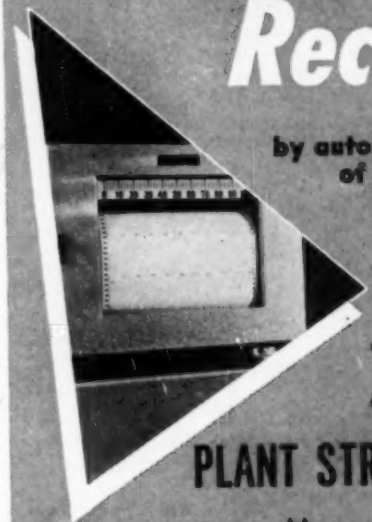

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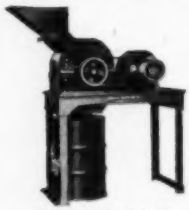

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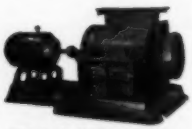

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LOCAL SECTION NEWS

(*Continued from page 69*)

NATIONAL CAPITAL

Technical Manpower Symposium

This Section held a symposium on Technical Manpower on Feb. 25 in the G.S.A. Building, the Interior Department (Old Building), Washington, D. C. Speakers on the program included Bernard Watson, of the Defense Manpower Administration, T. A. Marshall, Jr., executive secretary of the Engineering Manpower Commission of the E.J.C., and Dael Wolfle, director of the Commission on Human Resources and Advanced Training. Donald B. Keyes, chemical engineering consultant and for many years head of the chemical engineering division at the University of Illinois, served as moderator.

Dr. Keyes opened the Symposium with a talk titled, "The Technical Manpower Shortage—A Serious National Problem." He emphasized that America's strength and affluence depend upon the creative power of its men and women—among whom none are more important than scientists and engineers. The most urgent need of our times, he continued, is for the fullest use of the nation's manpower resources, both in civilian life and in the armed forces.

Dr. Keyes urged that the armed forces use engineers only in jobs in which their specialized skills are absolutely essential. Much can be lost, he added, if, in these times of acute manpower shortages, highly trained personnel are assigned to routine military tasks that might be capably handled by technicians. The current problems of scientific manpower, Dr. Keyes concluded, must be clearly presented to the public at large if the necessary solutions are to be found.

Bernard Watson then indicated that engineering graduates will be in short supply at least until 1955 and probably for some time thereafter. He further remarked that one of the most far-reaching effects of the defense program has been the acceleration of research and industrial technology. Likewise, the development, operation, and maintenance of modern scientific weapons have given increasing emphasis to military technology. As a result, industrial and scientific development, that normally would have been spread over a decade, now must be telescoped into less than half that time. Quoting from a recent report of the Office of Defense Mobilization, Dr. Watson said that during the past decade, the number of American scientists and engineers had risen about 60 per cent; that the ever-increasing complexity of the nation's economy and the rapid growth of research activity make it essential that this upward trend continue.

T. A. Marshall, Jr., stressed the need

for qualified science teachers in U. S. high schools. These teachers, he asserted, can do much to convince young people of the importance of science and engineering and at the same time can acquaint them with the vital part they can play in the advancement of these professions. Mr. Marshall urged engineers to speak before Parent-Teacher Associations, service clubs, fraternal organizations, and other community groups in an effort to familiarize the public with the achievements of the engineering profession. Above all, he maintained that every effort should be made to refute the three basic fallacies of current manpower thinking: (1) that military manpower alone accounts for the strength of the nation in time of peace, (2) that military manpower makes virtually the entire contribution to the winning of wars, and (3) that whatever scientists may be needed may be found in the residue of manpower after all military demands have been satisfied.

The Symposium was concluded by Dael Wolfle, who urged the U. S. high schools to make a more concerted effort to determine by tests and other methods those students who have the natural ability to succeed in college and in later professional careers. A broad scholarship program in the U. S., Dr. Wolfle estimated, might result in a 25 per cent increase in the number of competent young people in American colleges today. He said that although the percentage of male college graduates in the field of engineering was about 16.5 per cent in 1949, that figure dropped only to about 15 per cent by 1951. The recent decrease in total enrollments, he said, has been caused mainly by the reduced birth rates of the thirties and by the decline in the number of veterans attending college with financial help from the government.

Reported by Howard Sanders

ROCHESTER

The fourth meeting of the season was held Feb. 20, 1952, at Rundel Memorial Library. The speaker of the evening, Floyd F. Walkley, director of the technical division of the City Planning Commission of the City of Rochester, discussed in a general way the plans of the City of Rochester and of the State of New York to cope with the traffic problems within the city limits during the next 10 to 20 years.

There were approximately 30 people present at the dinner and 40 present at the meeting.

(More Local Section on p. 72)

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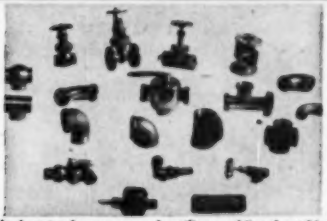

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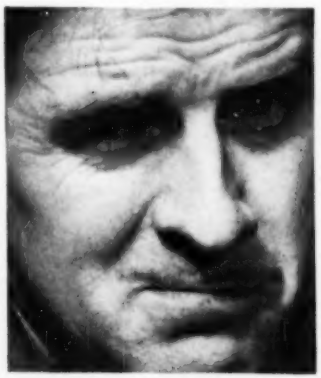

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ROCHESTER

(*continued*)

At the preceding meeting held Jan. 16, 1952, at Rundel Memorial Library, John Temmerman, City Chemist for the City of Rochester, discussed the chemical and legal aspects of the drunken driving problem.

There were approximately 35 people at the dinner and 80 people at the meeting.

Reported by Irving Siller

ST. LOUIS

A group of 102 members and guests attended the March 18 meeting at the York Hotel. Nelson W. Taylor of the Minnesota Mining and Manufacturing Co., spoke on "Fluorochemicals—New Materials for Industry."

Dr. Taylor introduced his talk with a brief summary of the early work on synthesis of fluorocarbons. He then discussed the Simons process, essentially the electrolysis of anhydrous hydrogen fluoride in which is dissolved the organic material to be fluorinated.

Reported by D. S. Weddell

CHICAGO

The annual social meeting took place at the Furniture Club in Chicago, March 5, at which 90 were present.

Featured was Sidney J. Harris, world-famous columnist whose articles appear daily in Chicago newspapers. Mr. Harris discussed "Great Books"; he explained that a study of remote and ancient times enables a person to evaluate the problems of the past from an objective rather than an emotional viewpoint. By applying the same techniques to modern problems a better understanding of our world may be attained.

Reported by Thomas A. Matthews II

MARYLAND

A meeting was held on Tuesday, March 11. The speaker was G. A. Fritzlen of the Haynes-Stellite Co., who talked on "High alloy and stainless steel corrosive resistance."

This Section held its regular monthly meeting Feb. 12, at Levering Hall, Johns Hopkins University. The meeting was preceded by a dinner.

Our speaker was William I. Burt, vice-president of the Goodrich Chemical Co. and President of the Institute. Mr. Burt spoke on Institute affairs, giving a summary of all recent events as well as a brief history and description of the functioning of various committees. Mr. Burt also spoke on the engineering manpower situation, stressing the critical shortage of chemical engineers.

Reported by L. C. Palmer

(*More Local Section News on p. 73*)

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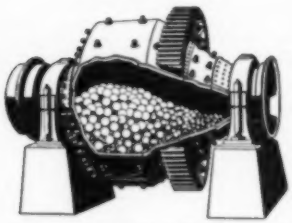
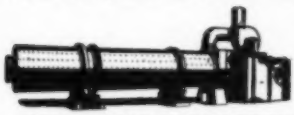
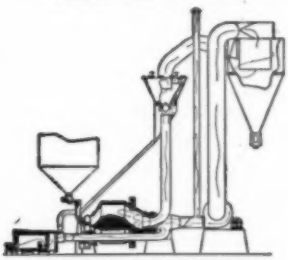
has it...



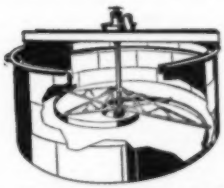
. . . BALL, PEBBLE AND ROD MILLS
(Conical, Tricone, Cylindrical.)
Write for Bulletin 17-B-40 (dry grind), AH-389-40 (wet grind), AH-414-40 (Tricone).



. . . RUGGLES-COLES ROTARY DRYERS, KILNS, COOLERS
Write for Bulletin 16-D-40.

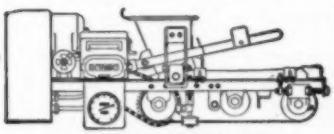


. . . AIR CLASSIFYING SYSTEMS
Write for Bulletin 17-B-40.



. . . THICKENERS OR CLARIFIERS
Write for Bulletin 31-D-40.

. . . WET CLASSIFIERS, HEAVY MEDIA SEPARATORS
Write for Bulletin 39-B-40.



. . . CONSTANT-WEIGHT FEEDERS
Write for Bulletin 33-D-40.

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LOCAL SECTION NEWS
(*Continued from page 72*)

CHARLESTON

The fourth meeting of the year was held Feb. 19, 1952, at the Charleston Recreation Center, with 140 members and guests present.

The speaker of the evening was G. H. Fremon of the research department of Carbide and Carbon Chemicals Co. Mr. Fremon spoke on synthetic fibers based on compounds containing the vinyl group. After mentioning their rapid growth in commercial importance and discussing some of the scientific aspects of their make-up, he described the ways in which they are produced. He then discussed in detail the properties of dynel fibers, made from vinyl chloride-acrylonitrile copolymer.

Reported by G. M. S. Connolly

COLUMBIA VALLEY

The Feb. 27 meeting of this Section was addressed by C. R. Gotjen of the Air Reduction Pacific Co., Seattle, Wash. His subject was "Aircomatic Welding of Stainless Steel and Aluminum."

The talk and accompanying color movie described the use and value of aircomatic welding which is a method of gas-shielded welding using a continuously fed filler wire.

Reported by Carl F. Falk

WESTERN NEW YORK

E. Dent Lackey, director of public relations of the Carborundum Co., and speaker at the March 13 dinner meeting, talked on "The History of the Carborundum Co." He attributed the founding of the company to the genius of Goodrich Acheson. Dr. Acheson was an understudy to Thomas A. Edison and experimented with Edison on the electric light bulb. Dr. Acheson made the first successive graphite filament and thereby obtained a background on the formation of graphite and the use of the electric furnace.

Dr. Acheson supervised the building of a number of electric light plants in the early stages of the use of electricity. At that time, Tiffany's was in search of an experimental process for manufacturing an abrasive cheaper than diamond dust. Dr. Acheson was intrigued with this problem and based on his experience with the electric furnace, he experimented with passing electricity through a mixture of coke and clay to produce hitherto unknown temperatures. In this experimentation, he made the first silicon carbide. He organized the Carborundum Co. to manufacture silicon carbide abrasives.

Reported by W. C. Greenwald

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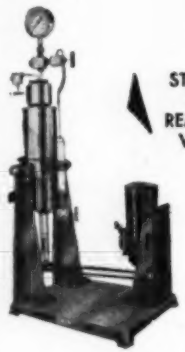

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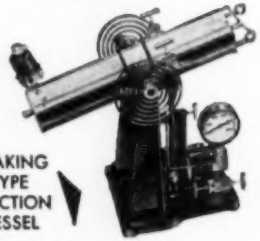

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FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York 7, N. Y.

MEETINGS

French Lick, Ind., French Lick Springs Hotel, May 11-14, 1952.
Technical Program Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.

Chicago, Ill., Palmer House, Sept. 11-13, 1952.
Technical Program Chairman: D. A. Dahlstrom, Chem. Eng. Dept., Northwestern University, Evanston, Ill.

Annual — Cleveland, Ohio, Hotel Cleveland and Carter Hotel, Dec. 7-10, 1952.
Technical Program Chairman: R. L. Savage, Dept. of Chem. Eng., Case Inst. of Tech., Cleveland 6, Ohio.

Biloxi, Miss., Buena Vista Hotel, Mar. 8-11, 1953.
Technical Program Chairman: Norman A. Spector, Vitro Corp., 233 Broadway, New York 7, N. Y.

Toronto, Canada, Royal-York Hotel, April 26-29, 1953.
Technical Program Chairman: Brymer Williams, Dept. of Chem. and Met. Eng., University of Michigan, Ann Arbor, Mich.

San Francisco, Calif., Fairmont and Mark Hopkins Hotels, Sept. 13-16, 1953.
Technical Program Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Annual—St. Louis, Mo., Hotel Jefferson, Dec. 13-16, 1953.
Technical Program Chairman: R. M. Lawrence, Monsanto Chem. Co., St. Louis 4, Mo.

SYMPOSIA

Vacuum Engineering
Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.
Meeting—French Lick, Ind.

Distribution of Chemicals
Chairman: D. A. Dahlstrom, Northwestern University, Evanston, Ill.
Meeting—Chicago, Ill.

Monobed Ion Exchange
Chairman: F. J. Van Antwerpen, Editor, Chemical Engineering Progress, 120 East 41st St., New York 17, N. Y.
Meeting—Chicago, Ill.

Applied Thermodynamics
Chairman: W. C. Edmister, California Research Corp., Richmond, Calif.
Meeting—Cleveland, Ohio

Human Relations
Chairman: R. L. Demmerle, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.
Meeting—Cleveland, Ohio.

Modern Statistical Methods in Chemical Engineering
Chairman: C. Daniel, Engineering Statistician, 116 Pinehurst Ave., New York 33, N. Y.
Meeting—Cleveland, Ohio.

Filtration
Chairman: F. M. Tiller, Dir., Div. of Eng., Lamar State College of Technology, Beaumont, Tex.
Meeting—Cleveland, Ohio

Chemical Engineering in Hydrometallurgy
Chairman: John D. Sullivan, Battelle Memorial Institute, Columbus, Ohio.
Co-Chairman: John Clegg, Battelle Memorial Institute, Columbus, Ohio.

Fluid Mechanics
Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Absorption
Chairman: R. L. Pigford, Div. of Chem. Eng., Univ. of Delaware, Newark, Del.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Walter E. Lobo, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

PEOPLE

William I. Burt, President of A.I.Ch.E. (1952) and vice-president, manufacturing, B. F. Goodrich Chemical Co., has completed 25 years of service with his company and its parent firm, The B. F. Goodrich Co. Mr. Burt joined B. F. Goodrich in Akron and soon afterward was named manager of its chemical plant there. When B. F. Goodrich Chemical was organized as a division of the Akron company in 1945, Burt was elected to his present post. He is a graduate in chemical engineering of Ohio State.

During World War II, Mr. Burt was on the engineering design committee of the Rubber Reserve Corp. for construction and operation of government rubber plants.

John O. Pritchard was recently made head of the new process evaluation division of the research department of American Potash & Chemical Corp. He graduated from the University of Wisconsin in 1941. From 1941 he was with the engineering department of the Du Pont Co. For seven years he served as a field engineer in process and development groups working with pigments and organic chemicals. For the past three years he was production supervisor at the Grasselli chemicals department plant of Du Pont at East Chicago, Ind.

A. J. Gracia affiliated with the office of the vice-president, Goodyear Tire & Rubber, has been named assistant manager of research and development activities. He joined Goodyear in 1928 following graduation from Massachusetts Institute of Technology. Assigned to research activities that same year, he was advanced to the post of chemical engineer and in 1942 was named manager of the chemical engineering division. During World War II he was in charge of chemical engineering for the company's synthetic rubber operations, and following the war was in charge of the chemical engineering development laboratories.

(Continued on page 76)

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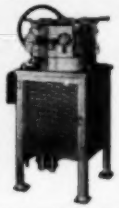

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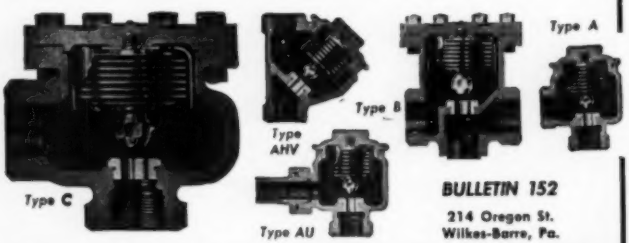

BULLETIN 152
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PEOPLE

(*Continued from page 75*)

Allen Latham, Jr., has been elected as a vice-president of Arthur D. Little, Inc., Cambridge, Mass. He will continue as technical director of the mechanical division. He went to Arthur D. Little, in 1941, after eleven years of technical and administrative experience, following graduation from M.I.T., in 1930 with a B.S. in mechanical engineering. After undergraduate study at M.I.T., Mr. Latham worked five years with Du Pont in West Virginia on process development at the synthetic ammonia plant. In 1941 he took a 12-month graduate course at M.I.T. in Business and Engineering Administration under the Sloan Fellowship Group of selected men who had had several years of industrial experience. **Leroy F. Marek** was named to the board of directors and will have charge of technical operations of the company.

Theodore A. Burtis, chief of the economics section of Houdry's research and development department since 1947, was recently made director of development. He is a graduate of Carnegie Institute of Technology and received his M.S. in chemical engineering at A. & M. College of Texas. Subsequently he was employed at Magnolia Petroleum Co. and Owens-Corning Fiber Glass Co.

Arno C. Fieldner, chief fuels technologist, U. S. Bureau of Mines, Washington, D. C., was recently presented with an honor award by the Washington Society of Engineers. Dr. Fieldner is the author of more than 400 monographs, bulletins, articles and technical publications on fuel testing and research. Affiliated with ASTM since 1914, he is a past-president and honorary member of the Society.

Fred E. Herstein has been appointed sales and engineering representative for Niagara Filter Corp., Buffalo, N. Y. He has been operating for the past year and a half as a chemical equipment sales representative. Prior to that time, he was associated with the chemical equipment division of General Ceramics and Steatite Corp., in the sales and engineering department.

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COLEMAN
INSTRUMENTS
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James C. Richards, Jr., has been elected vice-president, sales, of B. F. Goodrich Chemical Co. Richards, who had been manager of international sales, joined B. F. Goodrich in 1934 as a chemist in the general chemical laboratories in Akron.

From 1935 until 1938 he was a chemical engineer working on reclaim rubber, then general foreman of certain Akron Plants for five years. He became production manager of the government's synthetic rubber plant at Louisville, operated by B. F. Goodrich and in 1944 appointed plant manager of the government plant at Borger, Tex., also operated by the company. In 1946 Richards was named head of the Hycar Rubber and Chemical Sales department of B. F. Goodrich Chemical, and became manager, international sales in 1949.

Bradley Dewey, Jr., vice-president in charge of the CRYOVAC division of Dewey and Almy Chemical Co., Cambridge, Mass., has been elected a director of the company.

George E. Field has been named field sales manager in the plastic materials sales department of B. F. Goodrich Co., Cleveland, Ohio. A graduate of Case Institute in chemical engineering, Field joined the B. F. Goodrich Co. in 1942 as production manager and subsequently became plant manager of the American rubber plant operated for the government in Louisville, Ky. He also served as technical manager and coordinator of all plants operated by B. F. Goodrich Chemical Co. in 1947 and technical service manager on Geon plastics in 1948.

Jack C. Dart has been made manager of research and development at Houdry Laboratories, near Marcus Hook, Pa., where he was director since 1947. Before joining Houdry, he served in various engineering capacities with Standard Oil Development Co., Magnolia Petroleum Co., Pan American Refining Corp. and Universal Oil Products Co.

George O. Curme, Jr., vice-president in charge of all research activities of Union Carbide and Carbon corporation, has been elected a director. He has been honored by many awards in the field of chemistry.

Gwyn Benson, director of plant research for Shawinigan Chemicals Limited since 1944, has been appointed European technical representative. He left for London early in March.

(Continued on page 78)

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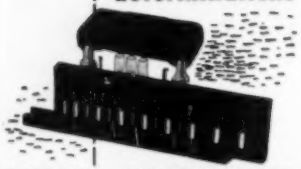

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William H. Thalheimer, associated with the Du Pont Co., Inc., since 1928, has recently been appointed manager of the Chattanooga plant. Previous to this appointment, he was employed as a chemist at the Jackson Laboratory of the organic chemicals department, Deepwater Point, N. J. Subsequently, after a year's leave to continue his university studies, he became a supervisor at the Chambers Works, Deepwater Point, in 1933. In 1943 he became assistant manager of the New Brunswick, N. J., fine chemicals plant; later he was appointed production manager of the fine chemicals division in Wilmington, and in 1949 returned to New Brunswick as plant manager.

Hubert N. Fiaccone, plant engineer at the Stonewall plant of Merck & Co., Inc., has been appointed manager of the new Flint River plant to be built at Elkton, Va., this year. A chemical engineering graduate from Syracuse University, he first joined Merck organization in 1942.

Ernest Ohsol of the General Electric Co.'s chemical division has been appointed manager of the new product development laboratory. Dr. Ohsol is a graduate of the College of the City of New York and holds degrees from Massachusetts Institute of Technology and the Swiss Federal Polytechnic Institute. Prior to his association with G. E. he was employed by the Standard Oil Development Co. as a chemical engineer.

Thomas Bamford has joined the technical economic group at Arthur D. Little, Inc., research and engineering organization of Cambridge, Mass. He received the B.S. and M.S. degrees in chemical engineering from Worcester Technological Institute in 1949 and 1950, and has done research development work at Lever Brothers Co. for the past year and a half.

James H. Lum has been selected by Monsanto Chemical Co. to attend the Advanced Management Program at Harvard University Graduate School of Business Administration. Dr. Lum, who is a director of Monsanto Chemicals (Australia), Ltd., was managing director of that company for four years beginning in 1947.

Lum has been with Monsanto since 1933. He was a group leader at the central research department, Dayton, Ohio, and held a similar position with the National Defense Research Council. He was engaged in research for the Manhattan Engineering District during World War II and was executive director of the Clinton National Laboratories at Oak Ridge, Tenn. He holds a B.S. degree in chemical engineering from Pennsylvania State College and a Ph.D. degree from Yale University.

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B. E. Thomas, associated with Monsanto Chemical Co.'s organic chemicals division since 1917 and production manager since 1943, has recently been appointed director of foreign manufacture. He was awarded an M.Sc. degree in chemistry by Rutgers University.

Ernest W. Reid, president of Corn Products Refining Co. since last April, has been elected to the board of directors of Commercial Solvents Corp. He joined the company in 1943 as vice-president in charge of the chemical and research division, and was elected a director in 1947. Immediately prior to his going with Commercial Solvents, he was associated with the War Production Board. He was also a member of the Council of National Defense, chief of the chemical branch of the Office of Production Management, and director of the chemical division of the War Production Board.

John R. Durland, plant manager of the Monsanto's division plant at Nitro, W. Va., was recently appointed assistant production manager. A graduate of Michigan Tech, he received a Ph.D. in organic chemistry from the University of Wisconsin in 1939.

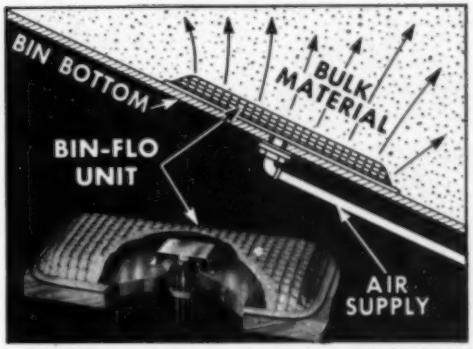
James R. Donnalley has been appointed section manager for the newly created silicone products department of the General Electric Co.'s chemical division. Prior to this promotion Dr. Donnalley was facilities engineer for the silicone manufacturing division.

Charles Harold Fisher, formerly with Calco chemical division of American Cyanamid Co. at Bound Brook, N. J., is now chemical engineer with the Atomic Energy Commission, Washington, D. C. In 1947 he was in the research and development department of Socony-Vacuum Oil Co., Paulsboro, N. J.

Thomas M. Moore has been promoted to group leader at the research laboratories of Standard Oil Co. at Whiting, Ind. He joined the company in 1946 as a chemical engineer. He is a graduate of the Illinois Institute of Technology.

Arthur W. Johnston has been named sales manager of Niagara Filter Corporation of Buffalo, N. Y. Mr. Johnston was formerly with the Buflovak division of Blaw-Knox Co. Prior to that he was with Worthington Pump and Machinery Corp. This appointment is part of a new program of expansion.

(More About People and Necrology on page 82)



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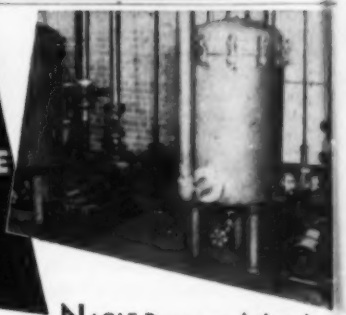

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CHEMICAL ENGINEER — Ph.D. Location Eastern Canada, with industrial research organization in the light metal field. Should be interested in design calculations for new processes and process development. Box 11-4.

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CHEMICAL ENGINEER — Experienced in handling design and erection for the complete plant as project engineer. Bulk of experience in detergents, pharmaceuticals, and organic chemicals. Seeking position as chief engineer. New York area. Box 1-4.

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CHEMICAL ENGINEER—M.S., 27, veteran, family. Sigma Xi. Research Fellow. Research Fellow. Experience in development department of large Midwestern chemical company including design, evaluation, development work. Desire development or production. Must be in Chicago area. Box 14-4.

CHEMICAL ENGINEER—M.S., 1949. Three years' experience in research and development. Published master's thesis. Navy electronic training. Desire responsible position in research, development, or pilot plant. Age 27, married. Excellent references. Box 15-4.

CHEMICAL ENGINEER—M.S. Eleven years' organics, intermediates, detergents engineering experience in design, development, construction engineering, economic analyses. Employed but desire challenging administrative position in production, engineering or development with a progressive, growing concern. Box 16-4.

HEAVY CHEMICALS—Age 49. Many years' experience in heavy chemicals production, as plant superintendent. Expert sulfuric, nitric and salts. Desire similar connection elsewhere or sales of chemical equipment. Box 17-4.

CHEMICAL ENGINEER—M.S. 1948. Project experience in dyestuffs, organic chemicals and adhesives. Design and specification of production units from development data. Chemical equipment purchasing, contractor negotiations and maintenance experience. Desire project or maintenance engineering. Box 18-4.

CHEMICAL ENGINEER — M.Ch.E., 1949. Three years' experience in research and development. Desire position in production, development, or pilot plant operations. N. Y.-N. J.-Conn.-Pa. area preferred. Married, veteran, age 26. Sigma Xi. Box 19-4.

CHEMICAL ENGINEER—M.S. (1947). Tau Beta Pi. Five years' experience research and development. Process development and pilot plant production of vitamins, enzymes, antibiotics, and detergents. Seek position in research or production. N. Y. C.; northern N. J. area. Box 20-4.

METALLURGICAL ENGINEER—Specializing in corrosion. Four years' wide industrial experience, emphasis on physical metallurgy. Four years' academic teaching. Doctorate in chem. eng. with research in metallurgy. Active professionally in major societies. Responsible position wanted. Box 21-4.

CHEMICAL ENGINEER—B.S., Ch.E. Age 28, family, veteran. Four years of practical, diversified experience in research and development. Desire a position which offers opportunity to advance to administrative position. Prefer Midwest or South. Box 22-4.

(*Continued on page 82*)

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PEOPLE

(*Continued from page 79*)

Elmer A. Meilun has been appointed a sales engineer in the New York office of the Buflovak Equipment Division of Blaw-Knox Co. Mr. Meilun, a chemical engineer graduate of Clarkson College, has been associated with Buflovak for the past four years and during this time he served in various capacities in the engineering department, including development, design and estimating. From 1945 to 1947 he was associated with the General Electric Co. as a chemical engineer in its phenol plant at Pittsfield, Mass.

Necrology

W. S. CALCOTT

William S. Calcott, special assistant to the director of the technical section of the Du Pont Co.'s organic chemicals department, died Feb. 15. He joined the chemical department of Du Pont in 1915.

CLASSIFIED SECTION

(*Continuation of page 81*)

CHEMICAL PROCESS ENGINEER—B.Ch.E. Age 33. Eleven years' experience in process design and plant development work in petrochemical, butadiene, ammonia, and nitrogenous fertilizer plants where knowledge of distillation, thermodynamics, absorption, heat transfer, etc., were required. Exceptionally well qualified through previous positions for economic evaluation of and development engineering for new projects. Present salary $10,000. Desire engineering position with small or medium-sized organic chemical or petroleum refining operating company. Box 23-4.

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INDEX OF ADVERTISERS

Page

A
American Instrument Co., Inc. 74
American Pulverizer Co. 70
Annin Co. 30

B
Babcock & Wilcox Co., Tubular Products Div. 25
Badger Process Div., Stone & Webster Engineering Corp. 26
Baird Associates, Inc. 69
Baker Perkins, Inc. 9
Bartlett & Snow Co., The C. O. 18, 19
Bin-Dicator Co. 79
Brookfield Engineering Labs., Inc. 72
Brown Fintube Co. 67
Buflovak Equipment Division 17
Byron Jackson Co. 38, 39

C
Climax Molybdenum Company 81
Coleman Instruments, Inc. 77
Cooper Alloy Foundry Co. 68
Corning Glass Works 31
Crane Company 6
Croll-Reynolds Company, Inc. 83

D
Davis Engineering Co. 70
Dorr Company 24
Dow Chemical Co. 36

E
Eco Engineering Co. 73

F
Fansteel Metallurgical Corp. 56
Fischer & Porter Co. 3
Fluor Corp., Ltd. 7
Food Machinery and Chemical Corp., Westvaco Chemical Div. 23
Foster Wheeler Corp. 43, 59
Foxboro Co. 84
Freeport Sulphur Co. 32

G
General American Transportation Corp., *Inside Front Cover*, 29, 35
Girdler Corp. 47
Glycerine Producers, Inc. 27
Great Lakes Carbon Corp. 16, 28
Gump Co., B. F. 80

H
Hammel-Dahl Company 48
Hardinge Company, Inc. 73
Hilliard Corp. 76
Hills-McCanna Co. 22

I
Instruments, Inc. 72

J
Johns-Manville 12, 65

L
Lapp Insulator Co. 40, 41, 66
Louisville Drying Machinery Unit, General American Transportation Corp. 35

M
Martindale Electric Co. 82
Miller, Inc., Ray 82
Minneapolis-Honeywell Regulator Co. 10, 11

N
Nagle Pumps, Inc. 79
National Carbon Co., A Division of Union Carbide and Carbon Corp. 4, 5
Niagara Filter Co. 20, 21
Nicholson & Co., W. H. 76

P
Parks-Cramer Co. 58
Pennsylvania Salt Mfg. Co. 60
Petro-Chem Development Co., Inc. 13
Pfizer & Co., Inc., Chas. 8
Prater Pulverizer Co. 72

R
Read Standard Corp. 61
Republic Flow Meters Co. 14
Rohm & Haas Company 53

S
Schnitzer Alloy Products Co. 71
Shriver & Co., Inc., T. 82
Sinclair Research Laboratories, Inc. 62, 63
Sorvall, Inc., Ivan 75
Sparkler Manufacturing Co. 54, 55
Spray Engineering Co. 75
Sprout, Waldron & Co., Inc. 46
Sterling Electric Motors 64
Stone & Webster Engineering Corp., Badger Process Div. 26
Struthers Wells Corp. 45
Swartwout Company 57
Swenson Evaporator Co., Div. of Whiting Corp. ..... *Back Cover*

Page

T
Taylor & Co., W. A. 78
Thermal Syndicate, Ltd. 77
Turbo-Mixer Division 29

U
Uehling Instrument Co. 83
Union Carbide and Carbon Corp., National Carbon Co. 4, 5
U. S. Gasket Co. 78
U. S. Stoneware Co. 160
U. S. Testing Co., Inc. 42

V
Vulcan Copper & Supply Co. ..... *Inside Back Cover*

W
Welsbach Corp. 15
Westvaco Chemical Div., Food Machinery and Chemical Corp. 23
Whiting Corp., Swenson Evaporator Div., *Back Cover*
Wiggins Gasholder Div. ..... *Inside Front Cover*

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The M-40 Auto-Selector has two measuring elements and control mechanisms — also a combined air relay. It actually does the work of two instruments . . . with one or the other variable under control at all times. The transfer of control from one variable to the other is smooth, instantaneous, and with no upset. Any type of control action may be used. Any combination of related variables may be controlled - pressure and flow; temperature and level; two flows; two pressures; etc.

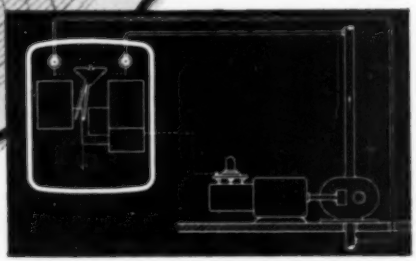

DIAGRAM *with accompanying chart above illustrates one of many applications. Pump drive is controlled to keep suction pressure from dropping below a set minimum, and discharge pressure from exceeding a set maximum. The instrument automatically controls from either variable as changing conditions require. On the chart, the outer record is for discharge pressure, the inner, for suction pressure.*

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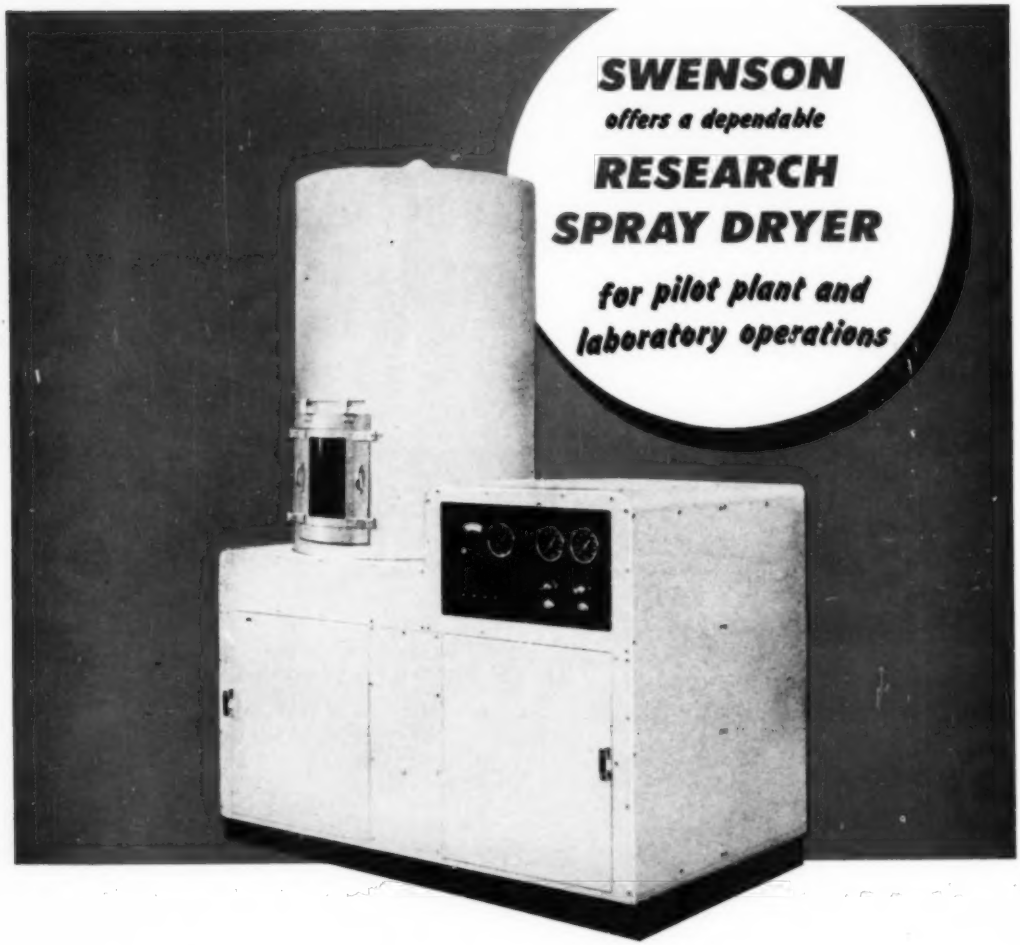

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